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EXECUTIVE SUMMARY

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DTU's undersøgelser af lav adhæsion / glatte skinner

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1. Opgaven

Nærværende undersøgelse af forekomsten af lav adhæsion / "glatte skinner" er en opfølgning på DTU's undersøgelser af IC4 togenes bremseadfærd ved Marslev den 7. november 2011, som blev gennemført for Transportministeriet og DSB i perioden april - juni 2012, og som konkluderede at den helt overvejende årsag til IC4 togets lange standselængde ved Marslev-hændelsen var lav adhæsion, det vil sige "glathed" mellem hjul og skinner. Afledt af dette resultat er der opstået en interesse og et behov for en bredere analyse af sikkerhedskritiske faktorer i forbindelse med togdrift, som belyser fænomenet adhæsion i almindelighed.

Adhæsion er et resultat af samspillet mellem tog, hjul og skinne. Dette samspil påvirkes af en række faktorer: dels af togets fremdrift, hjulet og skinnen (legering, slitage, krumning m.v.), og dels af "dét, der er imellem" hjul og skinne, det vil sige eventuelle belægninger på skinnen. Disse skinnebelægninger er resultat af klimatiske, geografiske og tidsmæssige faktorer og varierer således med vejr, sted og årstid.

Med henblik på en nærmere analyse af årsager og virkninger for dette samspil og dets betydning for sikker togdrift har Transportministeriet og DSB bedt DTU om at gennemføre nedenstående tre udredningsopgaver, som DTU har gennemført i perioden oktober 2012 – oktober 2013:

- En erfaringsindsamling med henblik på, hvordan andre lande i Nord- og Mellemeuropa håndterer lav adhæsion / "glatte skinner".
- En systematisk kortlægning af hyppighed og omfang af lav adhæsion / glatte skinner for togtyperne IC4 og IC3 i løvfaldsperioden 2012 på en række togstrækninger i hele landet med det formål at

undersøge, om der kan etableres et dynamisk ”landkort” over områder i Danmark med en øget sandsynlighed for periodisk forekomst af lav adhæsion, og dermed en relativ øget sandsynlighed for hændelser især i forbindelse med nedbremsning.

- En undersøgelse af adhæsions- / friktionsforhold mellem hjul og skinne under kontrollerede laboratorieforhold ved anvendelse af forskellige smøremidler (sæbe (som beskrevet i teststandard), olie og bladsaft) med det formål at afklare, om der er forskelle mellem IC3 og IC4 togets hjul, som har betydning for de to togtypers standseadfærd under de forskellige forsøgsopsætninger. Baggrunden herfor er, at IC4 hjul er lavet af en lidt ”blødere” stål-legering end IC3 hjul og undersøgelserne skal afdække standselængdens eventuelle afhængighed af dette forhold.

2. Overordnede resultater

Ekstrem lav adhæsion er en følge af ”et tredje lag” mellem hjul og skinne. Dette lag dannes af en kombination af let fugtighed og forurening (for eksempel løvrester, rust, olie, luftforurening m.v.), som sætter sig på skinnen. Ekstrem lav adhæsion kan optræde og forsvinde i løbet af meget kort tid og opstår tilfældige steder, dog er der områder med højere sandsynlighed for at der forekommer glatte skinner (for eksempel i skovområder med løvtræer). Prædiktion af, hvor og hvornår områder med lav adhæsion optræder, og hvor udstrakte de er, kan foretages med såkaldte stokastiske modeller.

Både internationalt og i Danmark er der implementeret tiltag, der skal reducere risici og gener ved lav adhæsion, dels for at mindske slitage ved slip/slide, dels for at fastholde regularitet i køreplanerne og endelig af hensyn til sikkerhedskritiske forhold.

2.1. Internationale erfaringer med håndtering af lav adhæsion

DTU’s gennemgang af en række nordeuropæiske landes erfaringer med den praktiske håndtering af lav adhæsion / glatte skinner viser, at der findes en række håndteringsstrategier og dertil hørende tiltag og foranstaltninger på forskellige organisatoriske niveauer og områder: 1) Detektering og prædiktion; 2) Tekniske løsninger ved toget; 3) Forebyggende foranstaltninger langs banestrækninger; 4) Foranstaltninger rettet mod lokoførere og operatører. Den optimale sammensætning af tiltag er afhængig af dels den nationale togdrift (frekvens, køreplaner, m.v.) og dels af landenes jernbaneinfrastruktur.

Fælles for alle undersøgte landes vedkommende er, at ansvaret for håndtering af glatte skinner er fordelt på flere parter (operatører, infrastrukturejere, m.v.). For at opnå en optimal effekt af de forskellige tiltag er det afgørende, at de ansvarlige organisationer afstemmer redskaber og deres anvendelse med hinanden med henblik på at undgå, at optimering af isolerede og ukoordinerede indsatser fører til et suboptimalt samlet resultat.

De internationale erfaringer tyder endvidere på, at hoveddrivkraften for de forskellige landes indsats mod glatte skinner primært er driftsrelateret, nemlig dels sikring af køreplan-regularitet, dels reduktion af slitage på hjul og skinner. Først i anden række motiveres tiltagene af hensynet til sikkerhed.

2.2. Danske tiltag

I Danmark er håndteringen af glatte skinner allerede i en årrække blevet betragtet som et fælles anliggende mellem infrastrukturforvalteren, Banedanmark (BDK), og alle jernbanevirksomheder, der kører på BDK's skinnenet. Der sker en koordinering mellem disse organisationer, primært med henblik på at sikre rettidighed i jernbanetrafikken og med fokus på løvfaldssæsonen (det vil sige fra 1/10 til 31/11). Af BDK's notat af 23. oktober 2013 fremgår[1] hvilke praktiske tiltag der aktuelt tages i brug:

- Vegetationskontrol langs sporene for at begrænse løv på skinner (BDK)
- Kørsel for at forhindre og opløse rustdannelser på skinnerne (BDK)
- Spuling af skinner for at rense skinnerne for eventuelle belægninger (BDK)
- Disponeringsplaner for afvikling af togtrafikken i løvfaldsperioden (BDK + jernbanevirksomheder)
- Instruktion af lokomotivførerne i kørsel under særlige forhold (jernbanevirksomheder)
- Vedligeholdelse af materiellets motorer og hjul (jernbanevirksomheder)
- Varslingssystem via togradio, som videregiver lokomotivførernes observationer til kollegaerne
- Systematisk opsamling af data om tog og evaluering af disse med henblik på en løbende optimering af forholdsregler og håndtering
- Systematisk registrering og analyse af data for signalforbikørsler siden 2006

Indsatsen er koncentreret på løvfaldsperioden og håndteres fra det fælles driftscenter for afvikling af togtrafikken på BDKs skinnenet (Driftcenter Danmark), som samler og analyserer data og koordinerer indsatsen.

2.3. Kortlægning af adhæsion i Danmark

DTU har gennemført empiriske undersøgelser med det formål at belyse, om en sandsynlighedsmodel for forekomsten af lav adhæsion kan etableres. En sandsynlighedsmodel er grundlag for at kunne forudsige et risikoniveau på baggrund af en række eksterne givne forhold, for nærværende undersøgelse er det blandt andet vejr, bevoksning, banelegemets karakteristika.

På det foreliggende datagrundlag er det muligt at konkludere, at en sådan model vil kunne opstilles. Imidlertid er der af tekniske årsager i øjeblikket ikke tilstrækkelig data til rådighed til udarbejdelse af en generel omfattende, landsdækkende model.

Der er i undersøgelsen således arbejdet med en proxy til bremsnings-slide, nemlig blokeringsinformationer fra togsystemet, det såkaldte "blokeringsflag". Blokeringsflaget er et signal, som registreres i togets log når en hjulaksel "glider" i forhold til skinnen.

DTU vurderer, at denne metode er fuldtud tilstrækkelig til at gennemføre analysen og at resultaterne herfra kan lægges til grund for de konklusioner som undersøgelsen kommer frem til.

[1] Banedanmark: Notat af 23.10.2013: Håndtering af glatte skinner i Danmark

Centrale resultater, som kan uddrages af de foreliggende data er:

- Sandsynligheden for, at der optræder blokeringsflag afhænger af følgende forhold:
    - Meteorologiske forhold; dugpunkt, vind, fugtighed, nedbør m.v. (skinnernes glathed)
    - Togets hastighed i bremsningsøjeblikket
    - Togets bremsekraft
    - Skinnernes egenskaber i form af kurver samt stigninger / fordybninger
    - Løvfald

- Der er i de analyserede data signifikant statistisk understøttelse af, at blokeringsflag optræder oftere for IC4 tog end IC3 tog. Denne signifikans understøtter imidlertid ikke i sig selv en hypotese om signifikant forskel mellem IC3 og IC4 togs bremseadfærd i situationer med lav adhæsion, primært begrundet i det forhold, at det ikke har været muligt at få bekræftet, om IC3 og IC4 togenes computere registrerer blokeringsflag med samme følsomhed.

DTU vurderer, at en sandsynlighedsmodel for forekomsten af lav adhæsion kan etableres, både i og udenfor løvfaldsperioden, og for en vilkårlig skinnestrækning. Det vil i givet fald kræve en tilpasning af de data, der indsamles, primært en øgning af GPS-frekvensen, således at det bliver muligt at aflæse den faktiske deceleration af togene. Herudover er der brug for on-line adgang til de relevante meteorologiske forhold.

En løbende opdatering på aktuelle adhæsionsforhold langs banestrækningerne vil sætte operatørerne i stand til at udstede målrettede advarsler (både i tid og sted) og giver lokomotivførerne mulighed for at justere kørestil i forhold til adhæsionsforholdene, samt anvende eventuelle tekniske løsninger på selve toget for at afhjælpe gener og risici ved glatte skinner.

Pålidelige prognoser kan endvidere understøtte timingen af infrastrukturejernes igangsættelse af forebyggende foranstaltninger langs banestrækninger (for eksempel højtryksspuling af skinnerne, anvendelse af Sandite e.l.).

2.4. IC3 og IC4 togenes hjul

Blandt de faktorer, der kan påvirke et togs bremse- /accelerationsadfærd er toghjulenes beskaffenhed. Efter Marslevhændelsen har det været drøftet, om det forhold, at IC3 togets hjul er lavet af en lidt hårdere legering end IC4 togets kan være årsag til forskellighed i de to hjultypers bremseevne og dermed kan forklare, hvorfor der for IC3 togets vedkommende i løbet af de 24 år denne togtype har været i drift, ikke er registreret en hændelse svarende til den ved Marslev.

For at afklare dette har DTU gennemført en række tribologiske eksperimenter med både IC4 og IC3 hjul. Disse undersøgelser har udsat materiale fra IC4 og IC3 hjul imod materiale fra en skinne for flere smøremidler, (bladsaft, olie og sæbe), og registreret hjulenes friktionsadfærd. Resultatet af undersøgelserne er, at de to hjultyper ikke udviste signifikante forskelle i bremseadfærd under anvendelse af de forskellige smøremidler, hvorfor det konkluderes, at IC3 og IC4 hjulenes legering ikke ser ud til at være en væsentlig eller sandsynlig årsag til eventuelle forskelligheder i de to togtypers bremseadfærd. Dermed bidrager de to hjultypernes forskellige beskaffenhed ikke til nogen forklaring på, hvorfor en hændelse svarende til IC4 togets ved Marslev ikke er registreret for noget IC3 tog.

3. Rapporten vedrører ikke sikkerheden

Det skal bemærkes, at denne undersøgelse ikke påpeger - eller har registreret - sikkerhedsmæssige forhold (f.eks. signalforbikørsler) i forbindelse med lav adhæsion og hjulslip i undersøgelsesperioden. Undersøgelsen beskriver således alene sandsynligheden for at fænomenet hjulslip opstår under en række givne forudsætninger for de to undersøgte materieltyper (IC4 og IC3). Rapporten forholder sig således ikke til, om der er jernbanesikkerhedsmæssige problemer med de undersøgte materieltyper.

4. DTU's anbefalinger

På baggrund af ovenstående analyse- og undersøgelsesresultater anbefaler DTU følgende:

- I alle lande, der er omfattet af DTU's undersøgelse, findes der en række tiltag og foranstaltninger til håndtering af "glatte skinner". Det væsentlige i denne sammenhæng er koordineringen af de enkelte indsatser. De relevante parter bør derfor overveje – i forlængelse af det eksisterende samarbejde – at formulere en national strategi for adhæsionshåndtering, hvor man vurderer eksisterende og eventuelt nye tiltag og aftaler deres praktiske implementering, koordination samt opfølgning. Herefter vil konkrete opgaver kunne allokeres til eller aftales mellem relevante parter.

- På baggrund af resultaterne for DTU's undersøgelser er det DTU's vurdering, at der relativ let kan udarbejdes et landkort over strækninger i Danmark med øget risiko for periodisk forekomst af lav adhæsion. Derfor anbefales det, at der etableres et sådant landkort, og at dette gøres dynamisk med daglige adhæsionsudsigter, ved at inddrage variable så som aktuel temperatur, nedbør, dugpunkt m.m.

  DTU vurderer, at det vil være et værdifuldt grundlag for organisationernes beslutning om, hvornår og i hvilket omfang der er behov for varsling og håndtering af glatte skinner.

  Landkortet vil kunne indgå i grundlaget for en national strategi for adhæsionshåndtering og koordineret implementering af konkrete adhæsionshåndteringstiltag.

  Etablering af et (dynamisk) landkort vil kræve en tilpasning af dataindsamlingsprocedurerne (højere GPS frekvens) samt en udvidelse af geografi og tidsrum for indsamling af data.

- DTU's undersøgelser har godtgjort, at der kan etableres varslingssystemer. Der anbefales et enkelt og effektivt system for prædiktion og varsling, baseret på de foreslåede udvidede dataindsamlingsprocedurer og et pålideligt system til hurtig informationsdistribution til relevante aktører (infrastrukturejere, operatører, togførere).

- Set i lyset af den forventede fremtidige udvikling i togtrafik og togtyper på det danske skinnenet vurderes det, at både det dynamiske landkort og optimerede varslings- og informationsudvekslingssystemer vil være særdeles nyttige med hensyn til sikring af forhold som regularitet og driftssikkerhed.

5. Resultater for de enkelte arbejdspakker

5.1. Arbejdspakke C: Internationale erfaringer med glatte skinner

5.1.1. Formål

At indsamle erfaringer med håndtering af glatte skinner fra nordeuropæiske lande med lignende problemer.

5.1.2. Metode

Afholdelse af workshop med eksperter fra Tyskland, England, Holland og Sverige den 16. april 2013 på DTU. Indsamling og analyse af rapporter og videnskabelige artikler fra samme lande.

5.1.3. Resultater

DTU's systematiske gennemgang af en række nordeuropæiske landes erfaringer med den praktiske håndtering af lav adhæsion / glatte skinner leder til en overordnet opdeling af relevante foranstaltninger i:

Detektering og prædiktion:
Metoderne til detektering af glatte skinner omfatter både indrapporteringer fra lokoførere og automatisk registrering ved hjælp af WSP (Wheel Slide Protection, som svarer til en bils ABS), mens prædiktion generelt beror på vejrudsigter og empirisk kendskab til strækninger med høj sandsynlighed for forekomsten af glatte skinner.

Tekniske løsninger ved toget:
Tekniske løsninger, integreret i toget, omfatter blandt andet "sanders", som er beholdere med sand, som påføres skinnerne (manuelt eller automatisk) for at øge adhæsionen i nedbremsnings- og accelerationssituationer, og WSP systemer (s.o.), samt magnetskinnebremser, som bremser toget ved at en bremseklods ved elektromagnetisk aktivering trækkes ned mod skinnerne. Endelig er der Eddy Current Brakes, som bremser ved hjælp af magnetfelter. Disse er stort set uafhængige af den aktuelle adhæsion.

Forebyggende foranstaltninger langs banestrækningerne:
Forebyggende foranstaltninger omfatter blandt andet periodisk højtryksspuling af skinner med vand for at fjerne det lag, der er årsag til lav adhæsion, øgning af adhæsionen ved systematisk anvendelse af Sandite (et gel med indhold af sand) på skinnerne, samt langsigtede foranstaltninger, så som opstilling af hegn og mure for at holde blade væk fra skinnerne, nedklipning af buske og træer samt andre metoder til at kontrollere vegetationen langs banestrækningen.

Foranstaltninger rettet mod operatørerne og lokoførere:
Disse omfatter blandt andet uddannelse af lokoførerne i køreteknik, instruktioner, og efterårs-køreplaner.

I flere nordeuropæiske lande har man erkendt glatte skinner som et reelt problem, der kræver forskellige modforholdsregler, ofte afhængigt af konkrete forhold i det enkelte land. Man har f.eks. i Tyskland udstyret nye tog med sandingsanlæg, medens man i Holland ikke har samme logistiske muligheder for genopfyldning af sådanne anlæg og i stedet har udviklet en metode til hyppig præparering af skinner i samarbejde mellem infrastrukturforvalter og operatør.

5.1.4. Konklusioner

Udfordringen fra glatte skinner udgør et problem, der ikke er begrænset til en bestemt togtype (f.eks. IC4) og det kræver derfor en koordineret indsats baseret på en rimelig balance mellem risiko og investering af ressourcer. Indsatsen bør desuden baseres på en vurdering af hensyn til både *sikkerhed* og *regularitet.* Lav adhæsion påvirker regulariteten direkte (forsinket acceleration), og visse sikkerhedsorienterede tiltag kan reducere regularitet (reduceret hastighed, tidligere opbremsning). Der vil således være tiltag, som kan give en marginal eller usikker sikkerhedsgevinst, men som indebærer store omkostninger i regularitet (og/eller gene, produktivitet …), og som derfor næppe er retfærdiggjort. Omvendt findes der adhæsionsfremmende tiltag, som kan gavne både sikkerhed og regularitet, og som derfor kun skal vurderes udfra en afvejning af omkostninger og gavn.

Ingen enkelt af de løsninger, som de europæiske operatører og myndigheder anvender, er i sig selv tilstrækkelige til at løse problemet. Desuden er flere løsninger afhængige af, at flere andre forhold implementeres. Eksempelvis ville en genindførelse af sandingsanlæg kræve et velorganiseret system til genopfyldninger, medens en mere effektiv og hyppig præparering (højtryksspuling) af skinnerne med langsomt kørende specialtog, kan medføre alvorlige forstyrrelser af køreplanen.

Det vil derfor være nødvendigt at aftale og implementere en sammenhængende kombination af flere forskellige tiltag, som i flere tilfælde kræver koordination på tværs af forskellige jernbaneorganisationer.

5.1.5. Anbefaling

DTU's kortlægning af internationale erfaringer omfatter ikke de konkrete tiltag, som faktisk er implementeret eller planlagt i Danmark. Rapporten kan derfor ikke i sig selv begrunde konkrete tiltag eller anbefalinger.

Der er i forvejen samarbejde mellem de berørte parter i Danmark om håndtering af lav adhæsion[2]. De internationale erfaringer indikerer ligeledes at koordinering mellem de mange forskellige organisationer er nødvendig. Problemer med lav adhæsion går på tværs af de organisatoriske skel, der er opstået med opløsningen af tidligere tiders monopol og tiltag for at etablere et frit marked for togdrift, og derfor er et tæt samarbejde ikke bare naturligt men nødvendigt. Afhængigt af, hvor tæt det eksisterende samarbejde er, bør det overvejes at etablere en national strategi for håndtering af lav adhæsion, som indebærer at overordnede formål, delformål og tekniske og organisatoriske tiltag aftales inden konkrete opgaver fordeles mellem de involverede parter.

[2] Banedanmark: Notat af 23.10.2013: Håndtering af glatte skinner i Danmark

5.2. Arbejdspakke A: Registrering og kortlægning af lav adhæsion / glatte skinner i DK

5.2.1. Formål

Formålet med arbejdspakkens empiriske undersøgelser var en afprøvning af muligheden for at etablere en sandsynlighedsmodel for forekomsten af lav adhæsion.

5.2.2. Metode

DTU's kortlægning af forekomster af lav adhæsion beror på en kobling af GPS data med DLU-log både for IC3 og IC4 tog. Data er indsamlet af DSB i løvfaldsperioden oktober-november 2012 på strækningen København-Aarhus. Yderligere er meteorologiske data benyttet, samt oplysninger om banelegemet, så som skinneforhold og vegetation.

Den anvendte model er en såkaldt logistisk regressionsmodel, hvor sandsynligheden for, at et blokeringsflag forekommer i data er modelleret via tog- og skinnekarakteristika (herunder den umiddelbart tilgrænsende vegetationen) samt meteorologiske variable (bl.a. temperatur, vind, dugpunkt, nedbør).

Det skal bemærkes, at den opstillede model på grund af mangelfuldt datagrundlag ikke direkte modellerer adhæsion, men derimod det såkaldte 'blokeringsflag', som optræder i DLU log data filer som proxy for at toget blokerer hjulene med efterfølgende 'slide' af disse til følge.

5.2.3. Data

1. DLU datalogs fra sensorer monteret på togene;
2. GPS-data logs fra GPS udstyr monteret på togene;
3. Data fra Strækningsregisteret for at estimere afstand fra Københavns Hovedbanegård;
4. Data om spornumre fra BDK, som bruges til at estimere hvilket spor der køres på;
5. Data om sporkrumning fra Kurveregisteret;
6. Data om elevation / fordybning fra BDK;
7. Data om vegetationen langs sporene fra BDK;
8. Meteorologiske data fra Dansk Meteorologisk Institut (DMI).

5.2.4. Antagelser og forudsætninger

Kvalitetssikring og co-registrering af data fra de mange forskellige kilder har vist sig udfordrende. Det har været nødvendigt at justere fremsendte data for hastighedsprofiler og bremseprofiler på grund af fejlagtige tidsmålinger. Det er DTU's opfattelse at de resulterende modificerede data giver et retvisende billede af hastigheds-og nedbremsningsforløb, men dette er dog en antagelse, som ikke fuldstændigt kan verificeres. Anvendelsen af de meteorologiske data indeholder fortsat et element af usikkerhed, som gør at de detaljerede resultater skal tages med forbehold. De overordnede resultater forventes dog ikke at blive påvirket af dette.

Ydermere har det vist sig, at den benyttede frekvens for GPS-oplysninger om togets position er problematisk i forhold til den nøjagtighed, som resultater fra en sådan undersøgelse må formuleres med. Afstanden mellem GPS datapunkterne er således relativt stor i forhold til den nøjagtighed som de øvrige data angives med.

Undersøgelsens konklusioner baserer sig på resultater fra togkørsler fra blot 11 forskellige dage. Man skal holde sig dette for øje ved generalisering til hele løvfaldsperioden.

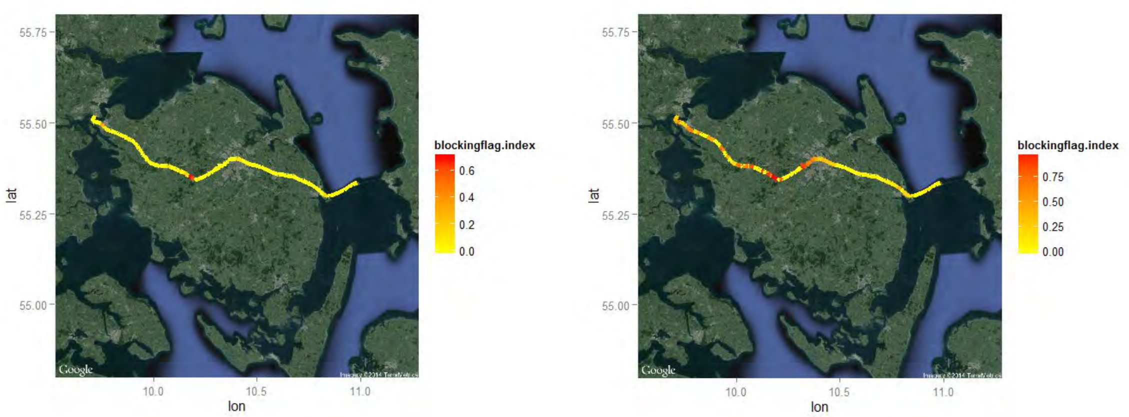
En fremtidig udvikling af et prædiktionssystem til lav adhæsion vil nødvendiggøre et mere robust datagrundlag.

5.2.5. Resultater

Analysen kan opsummeres i brede termer som følger:

- Det er muligt at modellere sandsynligheden for et blokeringsflag.
- Sandsynligheden for et blokeringsflag afhænger af:
    - Glatheden af skinnerne
    - Togets hastighed
    - Bremsekraften
    - Karakteristika for sporet i form af kurver samt hævninger/forsænkninger
- Én faktor, der signifikant påvirker glatheden af skinnerne, er løvfald.
- Den samlede effekt af de fundne effekter af togtype (IC3/IC4) viser en signifikant højere sandsynlighed for blokeringsflag for IC4 tog sammenlignet med IC3 tog, når der korrigeres for forskelle i hastighed, nedbremsning, baneforhold, meteorologiske omstændigheder samt løvfald. Denne signifikans er dog utilstrækkelig i sig selv til at understøtte en konklusion om signifikant forskel mellem IC3 og IC4 togs bremseadfærd i situationer med lav adhæsion, primært fordi det ikke har været muligt at få bekræftet, hvorvidt IC3 og IC4 togenes computere registrerer blokeringsflag med samme følsomhed, men også grundet det manglefulde datagrundlag.
- Med et tilstrækkeligt datagrundlag forventes det, at metoden kan udvides til, dels hele løvfaldsperioden, dels en vilkårlig skinneføring, også til tidspunkter udenfor løvfaldsperioden.

Som eksempel på mulighederne ses på figur 1 til venstre et kort over sandsynligheden for at initiere en blokeringssekvens for forholdende under en specifik togkørsel den 29. oktober 2012. Til højre ses et tilsvarende kort, hvor antagelsen er, at der køres med 180 km/h samtidigt med, at der bremses. Sidstnævnte kort viser således sandsynligheden, hvis der bremses på et vilkårligt sted langs banen, hvor førstnævnte kort viser sandsynligheden, hvor der aktuelt er blevet bremset på den aktuelle tur.



Figur 1.

Venstre side: Kort over sandsynligheden for at initiere en blokeringssekvens for en faktisk togkørsel, den 29. oktober 2012. De røde områder viser de strækninger, hvor der faktisk skete nedbremsninger og modellen viser at sandsynligheden for et blokeringsflag blev beregnet til at være høj (populært sagt: der kunne forekomme slide). Sandsynligheden for et blokeringsflag er selvsagt 0, hvor der ikke bremses.

Højre side: Kort over sandsynligheden for at initiere en blokeringssekvens for samme togkørsel. Nu under den antagelse, at *toget kører 180 km/h på hele strækningen og der nedbremses (bremseniveau 2.5) på hele strækningen* (populær forklaring: man kan forestille sig "der forsøges bremset en gang i sekundet"). De røde områder viser de strækninger, hvor modellen tilsiger, der er forøget sandsynlighed for at der kan forekomme slide. Modellen kan altså udtale sig om strækninger, hvor der ikke normalt bremses.

De terrænmæssige og de meteorologiske forhold ved de to kort er de samme, eneste forskel er "kørestilen".

Bemærk: for at fremhæve de forskellige skinnestrækninger visuelt er farveskalaen fra gul til rød for venstre figur 0-0.7 og for højre figur 0-1.0. Dette er et udslag af at køre 180 km/h på hele strækningen og have bremseniveau 2.5 på hele strækningen, hvilket naturligvis ikke er sket for den faktiske kørsel.

Figurerne illustrerer godt, hvordan modellen kan bruges prædiktivt under forskellige scenarier: fx med ændret kørestil, ændrede meteorologiske forhold, og ændrede terrænmæssige forhold.

5.2.6. Konklusioner

DTU vurderer at en sandsynlighedsmodel for forekomsten af lav adhæsion kan etableres. For at en sådan model kan blive generelt anvendeligskal dataopsamlingen forbedres. Blandt andet er en øgning af GPS-frekvensen vigtig for at man kan måle den aktuelle deceleration af toget. Yderligere er on-line access til meteorologiske variable nødvendig.

5.2.7. Anbefalinger

Muligheden for at kunne håndtere udfordringerne med lav adhæsion på hurtig, målrettet og effektiv måde afhænger af kvaliteten og pålideligheden af de anvendte metoder til detektion og prædiktion af lav adhæsion under togkørslerne, samt den hastighed hvormed varslerne kan udbredes til de relevante operatører. En kontinuert opdatering om faktiske forhold med lav adhæsion langs sporerne vil tillade operatører at udstede målrettede varslinger I forhold til både tid og sted. Dette vil give lokomotivførerne mulighed for at tilpasse kørestilen til lav adhæsions forhold, samt iværksætte tekniske foranstaltninger ved toget for at imødekomme gener og risici ved lav adhæsion.

Pålidelige prognoser vil endvidere muligøre optimal udnyttelse af præventive tiltag fra den infrastrukturansvarlige som fx højtryksspuling, behandling med Sandite, etc.

Udarbejdelsen af et praktisk anvendeligt varslingssystem vil skulle basere sig på en fornyet og tidsmæssigt mere omfattende dataindsamling (blandt andet en langt højere GPS frekvens) end det i undersøgelsen anvendte datasæt.

Det er DTU's opfattelse, at det er relativt nemt at udvikle et landkort over strækninger i Danmark med forhøjet sandsynlighed for forekomst af glatte skinner og et tilhørende varslingssystem. Derfor er det

DTU's anbefaling, at en større dataindsamling bør initieres med dækning af relevante strækninger over hele landet og for alle årstider. Dette vil så kunne danne grundlag for opbygningen af et dynamisk kort til prædiktion og varsling af lav adhæsion.

5.3. Arbejdspakke B: Tribologiske undersøgelser

5.3.1. Formål

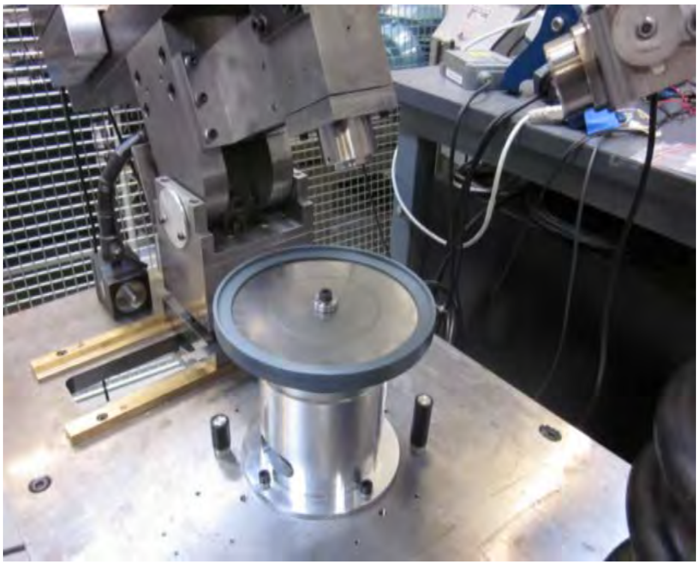
For at undersøge om friktionsforholdene mellem hjul og skinne på IC4-toget adskiller sig fra forholdene for IC3-toget er der foretaget en række eksperimentelle undersøgelser, hvor hjulmateriale fra hhv. IC4- og IC3-tog sammenlignes.

5.3.2. Metode

Undersøgelserne udføres på en "Pin-On-Disc"-testmaskine (se figur 2.). Denne type testmaskine er almindeligt anvendt til eksperimentel måling af friktionskoefficienter i industrien og på universiteter. Discen roterer med en forudbestemt vinkelhastighed og pinden trykkes med en kendt kraft mod discen. Det nødvendige moment til at rotere discen måles og friktionskoefficienten kan bestemmes.

Skinnematerialet af typen UIC 60, som bl.a. ligger på banestrækningen ved Marslev, anvendes som "disc" (se figur 3). Hjulmaterialet for IC3 er R8T stål, og for IC4 er det R7T stål. Begge ståltyper er almindeligt anvendte som hjulmaterialer. Hjulmaterialet indgår i testen som "pin" (se figur 4).

Forskellige "smøremidler" påføres "discen", for at simulere de forhold der er tilstedet når der er glatte skinner; bladsaft, smørefedt, flydende sæbe og rapsolie.



Figur 2. Pin on disc test rig.

Figur 3. Test disc.

Figur 4. Test pin.

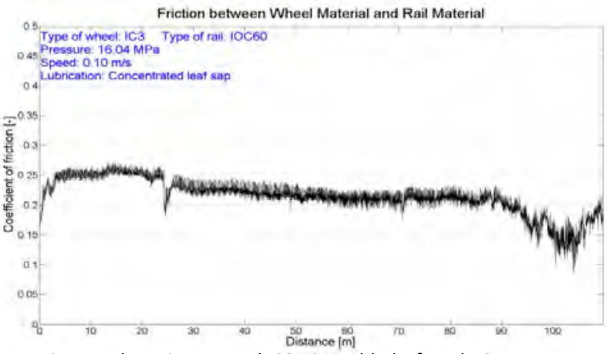
5.3.3. Antagelser og forudsætninger

Forsøgene er udført ved en relativ hastighed mellem pin og disk, der svarer til at toget kører med hastigheden 36 km/t og bremser med 1 % slip. Forsøgene er udført ved en temperatur på ca. 20°C.

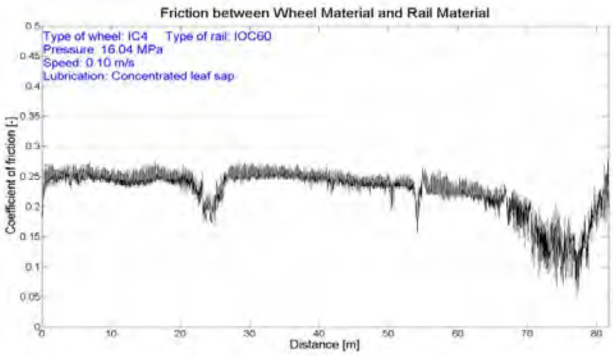
5.3.4. Resultater

Forsøg med bladsaft som smøremiddel (bøgeblade)

På figur 5 og figur 6 ses udviklingen i friktionskoefficienten for henholdsvis IC3-pin’en og IC4-pin’en, ved et kontakttryk på 16MPa. Friktionskoefficienten begynder at falde markant efter 90 meter i tilfældet med IC3-pin’en og efter 65 meter i tilfældet med IC4-pin’en. Dette fald i friktionskoefficienten sker samtidig med at bladsaften er tæt på udtørring. Den efterfølgende stigning i friktionskoefficienten sker efter bladsaften er udtørret.



Figur 5. Eksperiment med IC3-pin og bladsaft ved 16MPa.

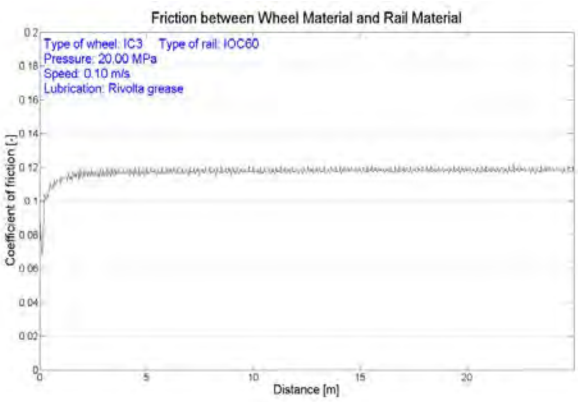


Figur 6. Eksperiment med IC4-pin og bladsaft ved 16MPa.

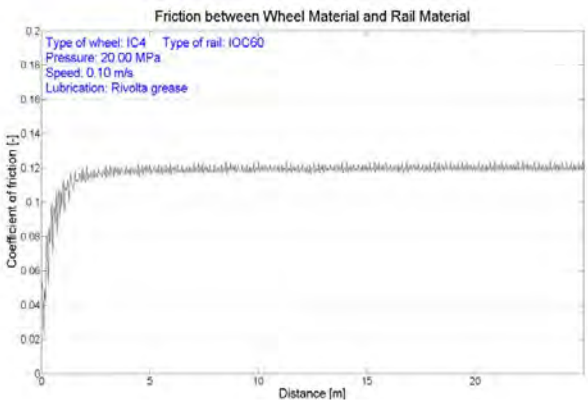
Forsøg med bladsaft er imidlertid ikke velegnede til at sammenligne de to hjulmaterialer, idet det er vanskeligt at skabe eksakt de samme forsøgsbetingelser fra forsøg til forsøg.

Forsøg med Rivolta smørefedt

Figur 7 og figur 8 viser graferne for forsøgene foretaget med Rivolta smørefedt ved et kontakttryk på 20MPa. Disse forsøg viser ikke nogle signifikante forskelle på de 2 hjulmaterialer med hensyn til friktionskoefficienten.



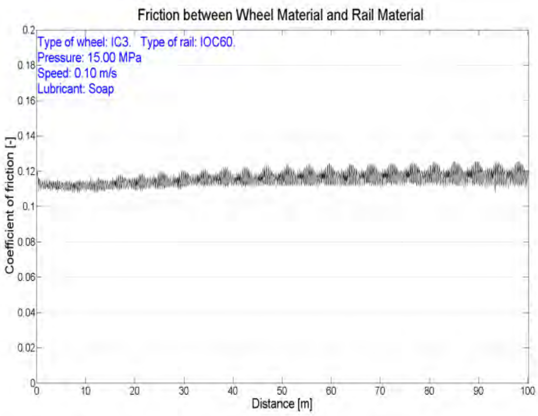
Figur 7. Eksperiment med IC3-pin of Rivolta smørefedt ved 20 MPa.



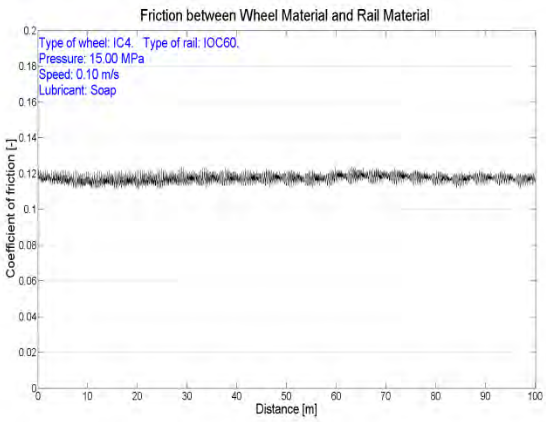
Figur 8. Eksperiment med IC4-pin of Rivolta smørefedt ved 20 MPa.

Forsøg med flydende sæbe som smøremiddel

På figur 9 og figur 10 ses graferne for henholdsvis IC3 og IC4-forsøget, udført med flydende sæbe som smøremiddel, ved et kontakttryk på 15MPa. Denne type sæbe har tidligere været anvendt ved fuldskalaforsøg ved Vojens. Forsøgene med sæbe viser ikke signifikante forskelle på IC3- og IC4-pin'en med hensyn til friktionskoefficienten.



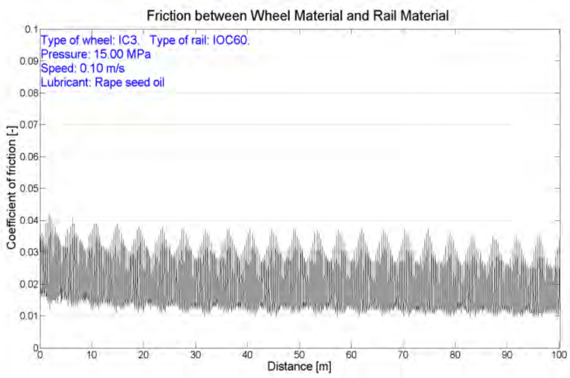
Figur 9. Eksperiment med IC3-pin og flydende sæbe ved 15 MPa.



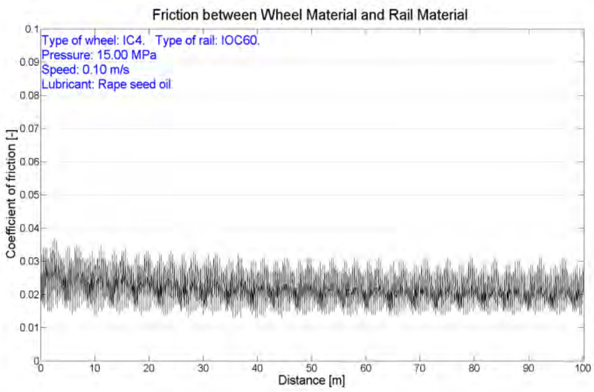
Figur 10. Eksperiment med IC4-pin og flydende sæbe ved 15 MPa.

Forsøg med rapsolie som smøremiddel

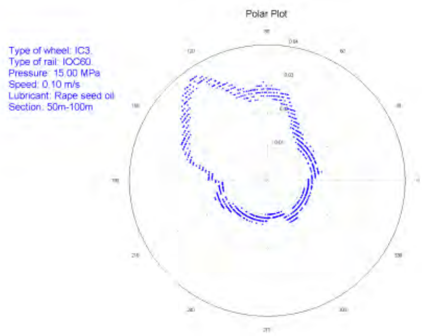
Rapsolie har, i lighed med sæben, været anvendt i fuldskalaforsøg ved Vojens. I mange af laboratorie-forsøgene med rapsolie ændrer friktionskoefficienten sig markant, alt efter hvor testdisc'en er i sin rotationscyklus. Eksempler på dette ses figur 11 og 12, og især på polar-plottene på figur 13 og figur 14. På grund af disse udsving i friktionskoefficienten, vurderes det at forsøgene der er foretaget med rapsolie, ikke er et velegnede som sammenligningsgrundlag for de to hjulmaterialer.

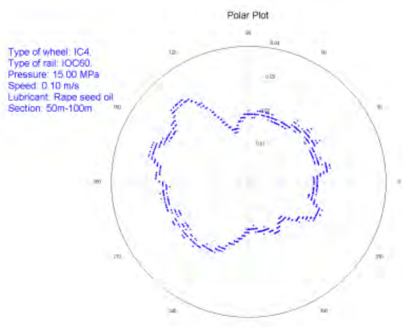


Figur 11. Eksperiment med IC3-pin og rapsolie ved 15 MPa.



Figur 12. Eksperiment med IC4-pin og rapsolie ved 15 MPa.



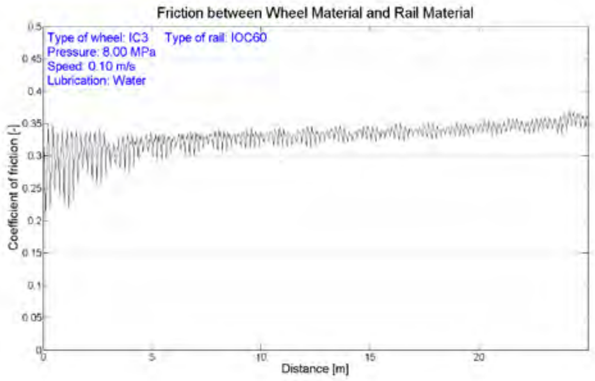


Forsøg med vand som smøremiddel

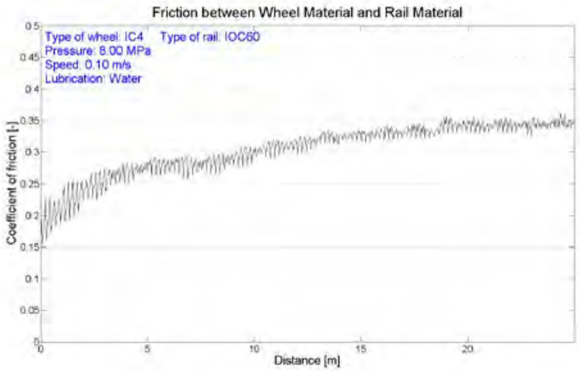
Figur 13. Eksperiment med IC3-pin og rapsolie ved 15 MPa.

Figur 14. Eksperiment med IC4-pin og rapsolie ved 15 MPa.

På figur 15 og figur 16 ses graferne for forsøgene med henholdsvis IC3-pin'en og IC4-pin'en, hvor vand er anvendt som smøremiddel. Friktionskoefficienten stabiliserer sig på omkring 0.35 for begge hjulmaterialers vedkommende. Til sammenligning er der i forsøgene med bladsaft målt friktionskoefficienter der ligger på 1/5 af friktionskoefficienten i forhold til forsøgene med vand.



Figur 15. Eksperiment med IC3-pin og vand ved 8MPa.



Figur 16. Eksperiment med IC4-pin og vand ved 8MPa.

5.3.5. Konklusioner

Der er ikke konstateret signifikant forskel på materialekombinationerne for hhv. IC3- og IC4-tog under de givne forsøgsbetingelser. Bremseevnen er således, hvad angår materialekombination mellem hjul og skinne, lige god for de to kombinationer.

Bladsaft i kontakten mellem hjul og skinne virker stærkt friktionsnedsættende ved bestemte koncentrationer af bladsaft. Friktionskoefficienten kan i ugunstige tilfælde reduceres til 1/5 af den normale.

Undersøgelser af friktionsforholdene baseret på anvendelse af sæbe eller smørefedt kan bruges ved sammenlignende tests, men afspejler næppe de forhold der opstår i forbindelse med "glatte skinner".

5.3.6. Anbefalinger

Testrækken har haft til formål at undersøge om friktionsforholdene mellem hjul og skinne på IC4-toget adskiller sig fra forholdene for IC3-toget, og danner således ikke basis for anbefalinger.

Analysis of the Probability for Blocking Flag Under Low Adhesion for IC3 and IC4 Trains, on the Route Copenhagen-Århus in the Leaf Fall Period.

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Contents

Executive summary.

DTU's mapping of incidences of low adhesion relies in a coupling af GPS data with DLU log data for IC3 and IC4 trains. Data are gathered by DSP in the leaf fall period October-November 2012, on the route from Copenhagen to Århus.

The basic task of these empirical investigations was an investigation of the possibility of establishing a probabilistic model for the occurrence of low adhesion. Due to technical reasons, the available data were insufficient to facilitate the development of such sufficiently general model. However, the resulting analyses of the current data point towards a number of interesting and informative contexts.

The model applied is a so-called logistic regression model, where the probability that a Blocking Flag occurs in data is modeled through train- and track characteristics (including surrounding vegetation), and environmental variables. It should be noted that, due to the nature of the available data, the modeled incident is the Blocking Flag, and not the phenomenon "low adhesion" directly. A Blocking Flag is a common event in the analyzed data, and it thus does not in itself point towards a situation where material or people are at risk. However, it does have economic consequences through rapid material degradation, just as the presence of wheels blocking over longer distances may lead to situations where there is risk of damage to material or people.

The analysis may be summarized in broad terms as follows:

- It is possible to model the probability of a Blocking Flag.
- The probability of a Blocking Flag depends on:
  a) Slipperiness of tracks;
  b) The speed of the train;
  c) The level of braking power;
  d) Track characteristics in terms of curves and elevation/recess.
- One factor that significantly affects the slipperiness of tracks with regards to Blocking Flag is leaf fall.
- The discovered evidence on the effect of train types (IC3/IC4) is insufficient to support a conclusion of an overall significant difference between IC3 and IC4 trains for what regards low adhesion, even though it does support a higher probability of a blocking flag for IC4 trains in the survey period, to the extent of the validity of the analyzed data.
- With suitable data available, it is expected that the method can be extended to both the entire leaf fall period and an arbitrary rail track, and also the time outside the leaf fall period.
- Reservations are taken for the current results, based on the quality of the available data.

DTU therefore assesses that a probabilistic model for the occurrence of low adhesion may be established in general. For such a model to be applicable in general, an adaption of the data gathering scheme is required, primarily an increase in the GPS frequency, to facilitate an actual observation of the deceleration of the trains. Furthermore, online access to environmental circumstances is needed.

The possibility of being able to handle challenges of slippery tracks in a fast, targeted and effective way depends crucially on the quality, and through that the reliability, of the methods that is used for detecting and predicting low adhesion during the train rides, as well as the speed with which such data are disseminated to relevant operators.

A continuous updating on actual low adhesion conditions along rail tracks will allow operators to issue targeted warnings, relating to both time and position, and give the train drivers the possibility of adjusting the driving mode of the train in accordance with the low adhesion conditions, as well as applying possible technical solutions in the train to address genes and risks with slippery tracks.

Reliable prognoses will support the timing of the launch of preventive measures from the owners of the infrastructure along the rail track, such as pressure washing of track, the deployment of Sandite, etc.

1. Introduction.

In the autumn 2012, a number of train rides were performed from Copenhagen to Jutland, to and possibly past Århus. Registry data from these train rides, in the form of log-data from the train computer, contains among other information a so-called *Blocking Flag*, which indicates if the wheels on the train blocks during braking, so that the train 'slides' along the track. It should be emphasized that a Blocking Flag is a relatively common event in the analyzed data, and as such doesn't point towards a situation where material or people are at risk. However, it does have economic consequences through rapid material degradation, just as the presence of wheels blocking over longer distances may lead to situations where there is risk of damage to material or people.

Data on GPS registrations of the trains' positions, the trains' speed and braking power, the train type (IC3/IC4 train), the physical surroundings such as vegetation, the curvature of the track, elevation/recess of the track relative to the surrounding area, and registration of environmental data in the form of temperature, precipitation, humidity, wind, turbulence and global radiation, has formed a basis for an analysis of the impact of these quantities on the probability of obtaining a blocking flag.

The analysis has focused on every time-point on the route where a braking has occurred. In these situations, the probability of a blocking flag has been modeled from train and track characteristics and environmental variables, at the time point and position where the braking has taken place.

The working hypothesis H of the analysis has been the following:

H: Slippery tracks increases the probability of a Blocking Flag

Since no obvious measure of the degree of slippery tracks is available, the environmental data together with the surrounding vegetation (which may result in leaves on the track which in turn implies leaf juice on the track), is used to model the level of slippery tracks, through a logistic regression model. The logistic regression model models the probability of a Blocking Flag when the train is braking, based on values for the environmental variables, the train characteristics and the track characteristics at a given time and place, and the model investigates the relations with this probability and the explanatory variables, with special emphasis on the working hypothesis H, and with special emphasis on characterizing differences in probabilities of blocking flag between IC3 and IC4 and their causes, if any.

The data obtained for use in the model are described in Section 2.1 below, while data manipulations and independent variables (input) for the logistic regression model are described in Section 2.2. The model itself and is described in section 3, while results are presented in Section 4. Finally, the results are discussed and elaborated upon in Section 5.

2. Data and data quality.

Data from 30 train rides from Copenhagen to Jutland were obtained. The initial study data schedule required three train rides per day, two IC3 trains and one IC4 train. However, this for was only available for eight days in the study period, which ranged from October 29, 2012, to November 29, 2012. The remaining three days where trains were run and data included in the study, only had two train rides per day. However, some of the datasets were incomplete, to a degree that rendered them unusable, as shown in Table 1. See section 2.2 for how this was handled.

Date 2012:	29/10	31/10	2/11	6/11	7/11	13/11	19/11	20/11	23/11	28/11	29/11	All	Used
Number of IC3 train rides:	2	2*	2	1*	2*	2*	2	1	1	2	2	19	15
Number of IC4 train rides:	1	1	1	1	1	1	1	1	1	1	1	11	11
Total number of train rides:	3	3*	3	2*	3*	3*	3	2	2	3	3	30	26

* : One of these train rides were not used in the analysis.

Table 1: Number of train rides that supplied data for the analysis, and the actual number of train rides used.

Individual train rides are numbered from 1 to 30 for their use in the analysis. In annexes, individual train rides are presented by numbers. For relationship between these numbers and dates, litra, recorded train number and train type (IC3/IC4), see Annex F.

Data for the analysis are comprised of the following components:

1. DLU data logs from sensors mounted on the trains;
2. GPS data logs from GPS tools mounted on the trains;
3. Data from the Track Register ("Strækningsregisteret" in Danish), to estimate the distance traveled from Copenhagen central station;
4. Data on track numbers obtained from Banedanmark, used to select the track curvature;
5. Data on track curvature from the Curve Register ("Kurveregisteret" in Danish);
6. Data on elevation/recess obtained from Banedanmark;
7. Data on vegetation next to the tracks, obtained from Banedanmark;
8. Data on environmental variables, obtained from Danish Meteorological Institute (DMI).

2.1 Description of datasets and their application.

The individual datasets and their uses are described in the following. Since data manipulation meant that a lot of data were left out of the analysis, the description of data as they are utilized in the analysis is different from the below. The reader is referred to section 2.3 for this.

2.1.1 DLU data logs.

The sensors recorded in the DLU log files are different for IC3 and IC4 trains, delivering different sets of information about each train type. In particular DLU log files for IC4 trains are both time- and event-driven, and thus takes a picture of the state of the train every time an event happens, which could be events completely unrelated to the concepts that is investigated in this report. At each of these event time points, data on the train status is recorded in the DLU log file. The data obtained from the DLU log files for this study were:

- Time Stamp;
- Speed;
- Braking power;
- Speed Surveillance (SpeedVHlog);
- Blocking Flag;
- Latitude of position;
- Longitude of position.

For IC 3 trains, the blocking flag was not truly a blocking flag as described in the introduction, but a flag for blocking *or slipping*, where 'slipping' indicates low adhesion under acceleration. This ambiguity is dealt with by relating the blocking/slipping flag to the handle position for braking/acceleration, which is negative for braking and positive for acceleration, and assuming that Blocking Flags relate to braking, while Slipping Flags relate to acceleration. The data were obtained for every time point where a registration had taken place in the DLU log. The DLU log files also contained a variable containing a 'travelled distance' estimate. This variable was not used first of all due to necessary data manipulations, as described in section 2.2, and second of all because the recorded travelled distance is a function of how many times the wheels have turned. In the event of slipping or sliding, this value will be an imprecise representation of the traveled distance.

The different sensors in IC3 and IC4 trains indicate that the data arrive in different patterns during the train rides. The recordings for IC4 trains are more comprehensive than for the IC3 trains, meaning that more events are recorded and thus more data are available for IC4 trains during a train ride from Copenhagen to Jutland, than for IC3 trains. The numbers of recordings in the DLU files, for the relevant dates, are summarized in Table 2. For description of the IC3 and IC4 DLU log files, see Annex 1 and 2.

The time spent on a train ride to Jutland is on average for IC3 trains 4.72 hours, and for IC4 trains 3.53 hours.

Train type	Log files	Minimum	Mean	Maximum	Time spent	Data per second:
IC3	19	1378	2466	3601	4.72h	1/7
IC4	11	31318	39721	45225	3.53h	3.1

Table 2: Number of registrations in the DLU log files for the dates in the study period.

2.1.2 GPS data logs.

In contrast to DLU data, GPS data are from the same the same type of equipment on both IC3 and IC4 trains, and therefore the order of magnitude in the number of data is similar between IC3 and IC4. However, the GPS data log files were much smaller than the DLU data files, which is apparent from Table 3.

Train type	Log files	Minimum	Mean	Maximum	Time spent	Seconds between data:
IC3	19	250	369	428	4.72h	46
IC4	11	188	269	380	3.53h	47

Table 3: Number of registrations in the GPS log files for the dates in the study period.

The data obtained from the GPS log files for this study were:

- Time Stamp;
- Speed;
- Latitude of position;
- Longitude of position.

2.1.3 Data from the track register ("Strækningsregisteret" in Danish).

In order to link the positions of the trains with the track characteristic, it is necessary to calculate the distance traveled from a fixed point source, which in the used version of the track characteristics are given as the distance to Copenhagen Central Station. The recordings on traveled distance in the DLU logs could not be used for this, first of all because of the data manipulations described in section 2.2, and second because some trains started at Copenhagen Central Station, while registrations of other trains started at Tårnby. To pinpoint the exact traveled distance, the track distance between Copenhagen Central Station and 40 stations on the route to Århus were obtained from the Track Register as the data recorded as "stationsmidte", ie. 'midpoint of station', with the intention of utilizing these distances as reference points. Manual calculations of track distance for a sample of stations confirmed that the "stationsmidte" variable adequately represents the true track distance from the 40 stations to Copenhagen Central Station. The used distances for these 40 stations are found in Annex E.

2.1.4 Data on track lanes.

On the train rides from Copenhagen to Jutland, multiple track lanes usually lie in parallel to each other, of which the train only uses one. When only two different track lanes are present, the train usually uses the right hand side lane viewed from the travel direction (Hanne Kiærulff, Banedanmark, personal communication August 21, 2013). However, in situations with multiple track lanes, for example in areas around stations and junctions where other railroad lines are encountered, it is not obvious which track lane that the trains use, and in some situations it varies with the train ride. The problem is illustrated in Figure 1 below taken from Krak.dk, which shows the railway track at Toftegårds Alle, Valby. Here, it is evident that the red S-train on the picture uses the upper lane, which is the right-most lane when the tracks are viewed east to west. It is well known that the trains that run to Jutland do not use the two northernmost track lanes on the picture. One of the northernmost lanes on Figure 1 curves northward shortly after Toftegårds Alle.

Figure 1: Track lanes around Toftegårds Alle near Valby Station. Source: Krak®/Eniro Danmark A/S.

The track lane has an impact on the curvature of the considered lane at a given position, in that it is not possible to assume that lanes at a given position curve in the same way (Hanne Kiærulff, Banedanmark, personal communication). To facilitate this problem, data has been obtained from Banedanmark on request, giving the lane that at any point on the route from Copenhagen to Århus should be considered as the lane that the train considered is most likely to use. These data are used to select the curvature of the track. The lanes are identified as the lane with the value “H” (for ‘Højre’/’Right side’) in the variable “SPORNUMMER_HVE” in the obtained data, and indexed with the traveled distance to Copenhagen until Fredericia Station, and the traveled distance from Fredericia Station after that.

2.1.5 Data on track curvature from the Curve Register.

Data from the curve register contains start and end points for curves on the railway track, indexed by lane number and distance from Copenhagen Central Station, or from Fredericia Station if the curve appears after Fredericia. Furthermore, a variable named “Strkafs” determines the position in the country, which determines whether the index is relative to Fredericia Station or Copenhagen Central Station. It has been necessary to cross-check the variable Strkafs for all curves with the Track Register/ ”Strækningsregisteret”, to determine if the index was relative to one station or the other, in particular because some curves have their starting point index relative to Copenhagen Central Station, and their end point index relative to Fredericia Station.
The curvature of every curve is determined through an approximating circle. The reciprocal of the radius of this circle determines the curvature of the track lane, so that the bigger the approximating circle, the lesser the curvature. To illustration, Figure 2 depicts the determination of the curvature of the curve *C* in the point *P*, where the curvature is *1/r*.

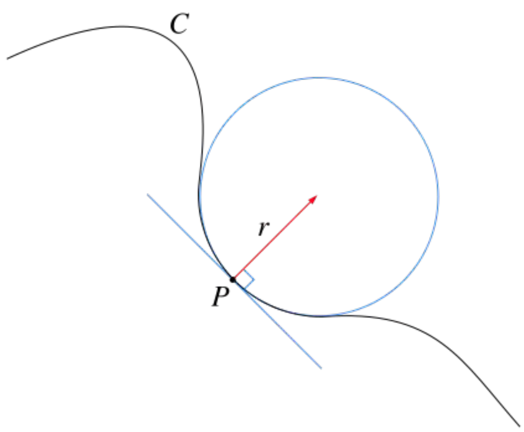

Figure 2: Curvature determination of the curve C in the point P, by use of an approximating circle with radius r.

In the extract from the curve register, the radius of the approximating circle is given in meters in the variable ‘Radius’ (see Annex 3), and the reciprocal of this variable, for the lane identified as the likely lane for travel (see section 2.1.4), is used as the curvature of any curve.

2.1.6 Data on elevation/recess.

Data on elevation and recess relative to the surrounding area was obtained from Banedanmark, indexed by distance from Copenhagen Central Station or Fredericia Station. It turned out that the positions in the data material were relative to a number of index points, and that the distances to Copenhagen Central Station for these index points were not directly obtainable. New data were acquired from Banedanmark on August 15, 2013. After quality check of these data, it has been necessary to correct the distance for 20 items, using corrected distances from Banedanmark. From this register, the following data were obtained, where reference station refers to either Copenhagen Central Station or Fredericia Station where appropriate:

- Presence of elevation/recess, relative to the right hand side of the track;
- Presence of elevation/recess, relative to the left hand side of the track;

- Level of elevation/recess on the right hand side of the track;
- Level of elevation/recess on the left hand side of the track;
- Start of elevation/recess in terms of distance to reference station;
- End of elevation/recess in terms of distance to reference station.

2.1.7 Data on vegetation next to the tracks.

Data obtained from Banedanmark contained

- start and end positions for areas of vegetation;
- whether the area was positioned to the right or left side of the track, or 'crossing';
- area in square meters of the vegetation area;
- vegetation type (forest, bushes or solitaire trees).

As with the data on elevation/recess, it turned out that the positions in the data material were relative to a number of index points, and that the distances to Copenhagen Central Station for these index points were not directly obtainable. New data were acquired from Banedanmark on August 15, 2013. After quality check, 12 items needed to have their positions corrected. Furthermore, the indicator for two groups of items (one around Vejle, and one around Roskilde) appeared to signify that the vegetation lay next to tracks not on the studied route. After consultation with Banedanmark/Lone Guldbrandt Jørgensen, the item group around Vejle was left out of the analysis, while the item group around Roskilde was kept, as it was still next to the track to Jutland despite being registered on another track (the Roskilde-Gadstrup track).

2.1.8 Data on environmental variables.

Data on environmental variables were obtained from the Danish Meteorological Institute (DMI) as follows. The train ride on November 2nd with train number 8107, litra 5657 was arbitrarily selected as reference ride, and the positions from the GPS log file (264 positions) were forwarded to DMI. For these 264 positions, values of environmental variables as described in Table 4 were obtained from DMI for every whole hour during the survey period, based on triangulation of model results in a 3 x 3 km grid across Denmark.

Name	Description	Scale
PRES	Accumulated Precipitation	Kg/m^2
T_2	Temperature at 2 meters' Height	Kelvin
TD_2	Moisture Indicator; Dew Point Temperature at 2 meters' Height	Kelvin
VS_10	Wind Speed at 10 meters' height	m/s
VD_10	Wind Direction at 10 meters' height	Degrees; 0-360° in a right rotated coordinate system with 0° being north.
TKE	Turbulent Kinetic Energy	m^2/s^2
GLOR	Accumulated Global Radiation	kJ/ m^2

Table 4: Environmental variables obtained from the Danish Meteorological Institute.

Notes to table 4:

- The accumulation of PRES and GLOR was done in 6 hours intervals, so that for each of the 264 positions and each 6 hour interval, 7 values were obtained. Of these 7, the 6 sequential differences were used so describe the one-hour level of precipitation and global radiation, respectively, so that t. ex. the value at 6 o'clock in the morning was taken to be the last value of the 6 differences from the 7-tuple that referred to the time frame 0-6 am, rather than the first of the differences that referred to the time frame 6-12 am. Thus, the value indicated the precipitation/global radiation over the last hour.
- The GLOR variable contains both direct and diffuse radiation that hits the surface.

For details on the model used by DMI, one is referred to Claus Petersen, Danish Meteorological Institute.

2.2 Data manipulation and description of model input.

The obtained data have been manipulated in several ways prior to statistical analysis, both due to standard rearrangements of data, but also due to poor data quality, in particular the DLU log data. Furthermore, the small number of GPS log data points relative to DLU log data points has meant that a number of approximations have had to be made, which makes the analysis imprecise. This is further discussed in section 2.3.

In order to make comparable studies of trains that run on the same route, the data were limited to the route from Copenhagen Central Station to Århus Station.

Furthermore, since recordings for some trains started at Copenhagen Central Station, and for others at Tårnby Station, the data were reduced to 2 km's after Danshøj Station: The routes from Copenhagen Central Station and Tårnby Station are gathered into a single route, shortly after Danshøj Station, see Figure 3. Because the statistical models uses data on vegetation up to 2km backwards on the track, 2 km after Danshøj Station was deemed the first point on the track from where trains from Copenhagen Central Station and Tårnby Station would have comparable environmental variables.

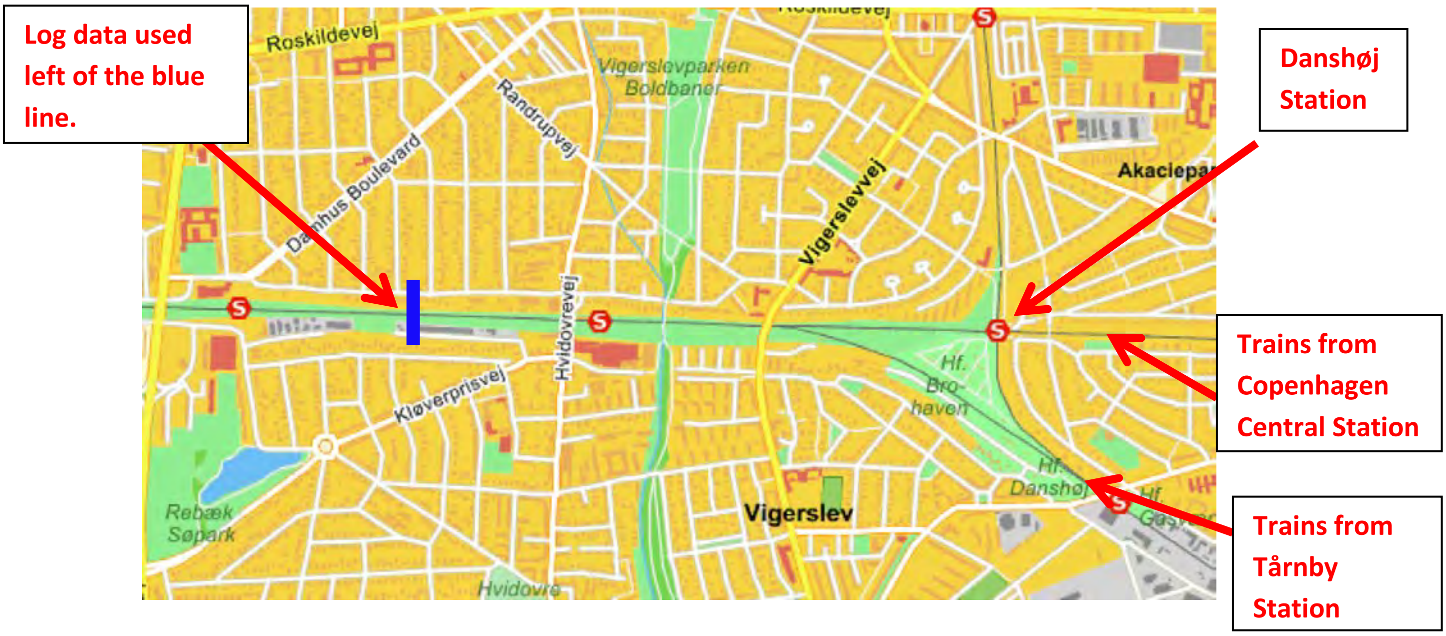

Figure 3: Start of registrations used in analysis. Source: Krak®/Eniro Danmark A/S.

2.2.1 DLU and GPS data logs.

After reducing the data as described, the Speed profiles for the 30 train rides were plotted from both GPS and DLU logs. When these were not aligned, a shift of one hour occurred. In these instances, a 1 hour correction was made to the DLU log time stamp, considering the GPS data as the correct ones. This was the case for two train rides.

2.2.1.1 Missing data in the train speed recordings.

The DLU log data suffered from missing data. For 4 train rides, the complete speed profile or a large part of it was comprised of obviously incorrect measurements of speed 0 (since the GPS log file showed that the train was moving), and registrations that were simply missing. An example of a partially missing speed profile is shown in Figure 4.

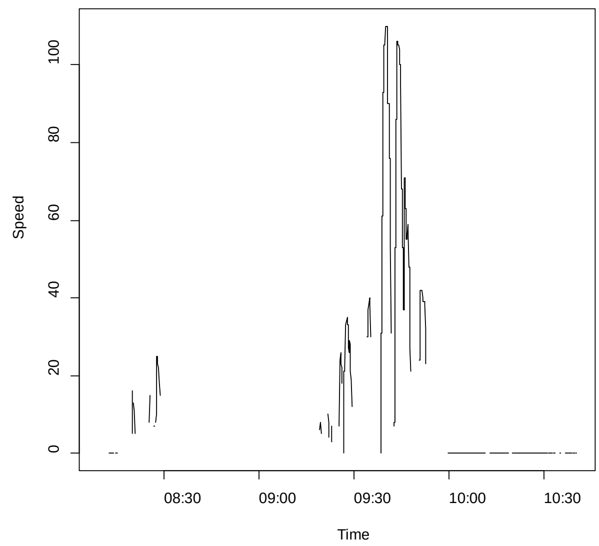

Figure 4: Speed profile for train number 23, litra 5053, on October 29th.

For these 4 train rides, the Speed registration was replaced by the variable SPEEDVHlog, which correlated strongly with Speed.

2.2.1.2 Backwards shifts in the DLU log time stamp.

Erratic registrations uncovered by the speed profiles persists. In Figure 5, another speed profile is plotted. It is clear from the proximity of large changes in registered speed that the data here are flawed.

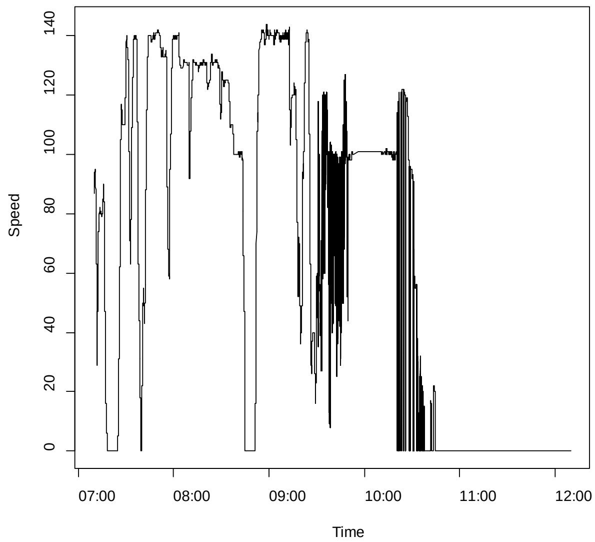

Figure 5: Speed profile for train number 5107, litra 5653, on November 13th.

The reason for this is uncovered by connecting the speed registrations in the sequence from the dataset from Banedanmark, rather than with increasing time stamps. This is shown in Figure 6 below.

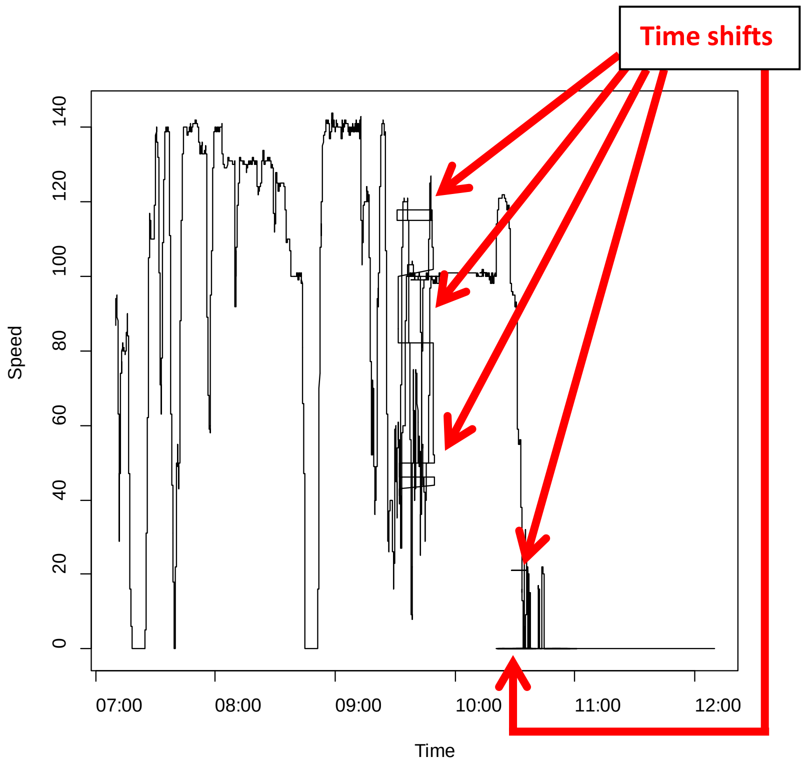

Figure 6: Speed profile for train number 5107, litra 5653, on November 13th. Plotted sequentially as data were received from Banedanmark.

It follows from Figure 6 that the time stamp is not contiguous. At a number of instances, marked by red arrows, the time stamp is shifted backwards in time. Some of these time shift has been explained by recorded balise telegrams, which shift the time by one hour. However, these only cover a fraction of the total number of time shifts found. It has not been possible to obtain an explanation for these erractic recordings from the data provider, apart from the balise telegrams. This phenomenon has previously been observed (Mogens Blanke, DTU, personal communication).

To counter the problem, all 30 speed profiles have been investigated for time shifts. It appears that often a backwards shift in time is followed by a similar forward shift, but it is not always the case, and in some situations the following forward shift does not have the same size as the backwards shift. The speed profiles were adjusted such that all backwards shifts were cancelled, and following forward shifts that sum to the same size as the backwards shift was likewise cancelled. The forward shifts following a backwards shift were identified as outliers in the differenced speed profile following the backwards shift. In Figure 7 below, the exemplified speed profile, cleansed for time shifts, is shown.

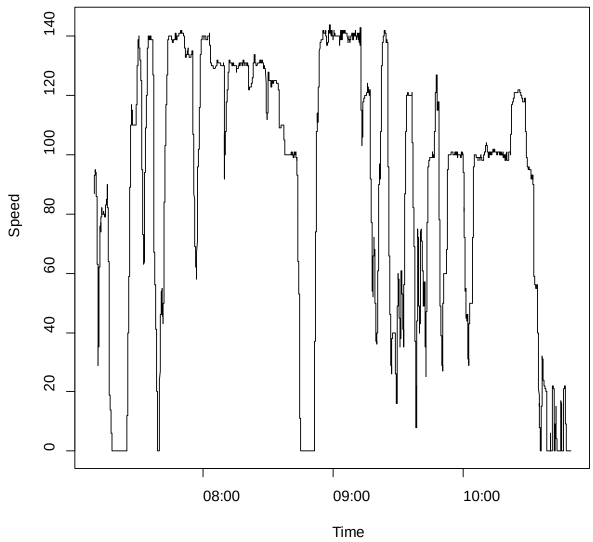

Figure 7: Speed profile for train number 5107, litra 5653, on November 13th, corrected for time shifts.

Time shifts occurred in 24 out of 30 train rides. In 11 of the 24 train rides with time shifts, the shifts could not be explained by balise telegrams. Not counting time shifts due to balise telegrams, 113 time shifts were cancelled following the described procedure.

2.2.1.3 Missing data in the train speed recordings.

In 4 train rides, no recordings of the train braking between Copenhagen and Århus have been made. For the statistical analysis, data are reduced to only the recordings where the train brakes, which leaves these train rides out of the analysis. 3 of these 4 train rides are identical to 3 of the 4 train rides that only had partial speed profiles recorded.

2.2.1.4 Re-aligning the traveled distance.

The DLU and GPS log are linked through the time stamps, which also links them to the environmental variables. However, in order to link the observations to the track characteristics and vegetation, it is necessary to calculate the distance traveled from Copenhagen Central Station for each observation, as this is what indexes track characteristics and vegetation. It is noted earlier that the recorded traveled distances in the DLU files cannot be used for this. However, it is also not possible to calculate this through measurements of time traveled and speed, because the GPS data only numbers a few hundred observations. Such an approximation will set straight lines through curves, and already at Glostrup Station, deviances from the actual distance of up to 500 meters have been found with this method.

Instead, the traveled distance from Copenhagen Central Station to 40 stations are found from the Track Register as described in Section 2.1.3. Between two such stations, the traveled distance is found for the GPS reference recordings by taking interpolation between GPS positions. For a given GPS position, λ is taken to be the percentage of the sum of the point-to-point traveled distances between the two stations. The traveled distance at the given point is then the convex linear combination given by λ of the traveled distance at the two surrounding stations.

For DLU log data, the distance traveled from Copenhagen Central Station for a given registration is found by identifying the GPS reference recordings (on November 2nd with train number 8107, litra 5657) immediately before and after. The distances to these two points are found through registrations of longitude and latitude, and the traveled distance is found as the proper weighted mean of the travel distances at the GPS reference positions.

2.2.2 Construction of inputs to the statistical analysis.

The summary of speed and braking power is listed in Table 5 below.

	Train Type	Minimum	Mean	Maximum
Speed	IC3	1	115.8	184
Speed	IC4	1	69.7	147
Braking Power	IC3	-8	-2.64	-1
Braking Power	IC4	-8	-2.76	-1

Table 5: Summary of speed and braking power.

It is noticeable that braking is registered as negative, since the braking power is equaled to a handle position, that takes values from -8 to -1 when braking.

The number of Blocking Flags is shown in Table 6 below. It should be noted that Blocking Flags typically occur in sequences, so that the probability of obtaining a Blocking Flag also depended on whether a sequence of blockings has been initiated. This is discussed in section 4.

Train Type	Blocking Flag	No Blocking Flag	All
IC3	107	6690	6797
IC4	2879	55417	58296
All	2986	62107	65093

Table 6: Blocking Flags.

The impact of vegetation is likely to depend on the wind direction. If, t. ex., the vegetation is placed to the right of the track lane and the wind comes from the left side, the wind will blow leaves away from the track and not onto it. Conversely, if the wind comes from the right, the wind will blow leaves onto the track, which may result in leaf juice on the tracks, implying the tracks to be slippery. The wind direction relative to the south-north axis is obtained from the environmental data, and to utilize this, it is necessary to find the angle with the track direction and this axis. After converting the reference GPS coordinates from latitude-longitude to UTM coordinates, the angle for the reference GPS data is found by taking the vector between the two neighboring reference points. In schematic form, this is illustrated in Figure 8.

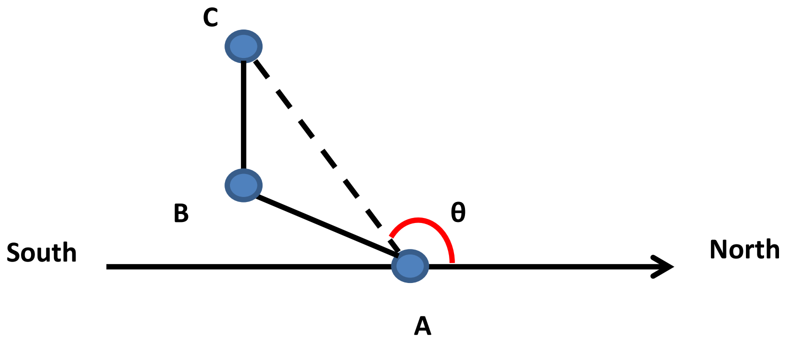

Figure 8: The track angle θ with the South-North axis for the point B, following Abut prior to C.

The angles for the DLU data are then obtained as convex linear combinations of the angles for the reference GPS registrations.

2.2.2.1 Construction of vegetation indexes.

To measure the amount of leaves that potentially may be blown onto the track, vegetation indexes for three forms of vegetation are constructed: Solitary trees, forest and bushes.
The Forest Index I_F is constructed as follows: At each position and corresponding time point, it is investigated if forest is present to the right of the track. If so, the forest patch in question has its area divided by its length, to estimate the thickness of the patch. The thickness index T is then assessed such that the impact of trees decreases linearly with the distance from the track, until 30 meters of thickness. A thickness of 30 meters thus gives T=1, while a thickness of 15 meters gives T=3/4, and a thickness of 10 meters yields T=4/9. Let θ_W and θ_T denote the angle for the wind direction at the given time point and the track, respectively, and let T_R, T_L denote the thickness index to the left and right of the track, respectively. The vegetation index I_F for forest is then calculated as

$$I_F = |\sin(\theta_W - \theta_T)|\left(T_R 1_{\{\sin(\theta_W - \theta_T)<0\}} + T_L 1_{\{\{\sin(\theta_W - \theta_T)>0\}\}}\right)$$

where the comparison of θ_W and θ_T is modulo π, and where sin() is the sine function.

The index I_B for bushes is computed in a similar fashion, but with a 10 meter linear decrease rather than the 30 for trees, while the index I_S for solitary trees is based on simple presence of solitary trees.
Vegetation indexes for vegetation over the last 500 meters, the last 1 km and the last 2 km of the track prior to the current position was constructed by averaging the thickness index over the relevant track section, and using the current wind direction as above. The indexes are summarized in Table 7 below, with respect to the data used in the logistic regression analyses.

Vegetation	Direct position		500 meters back		1 km back		2 km back	
	%positive	Mean	%positive	Mean	%positive	Mean	%positive	Mean
Forest	11%	0.21	22%	0.11	32%	0.08	47%	0.06
Bushes	5%	0.35	11%	0.15	12%	0.09	14%	0.05
Trees	0.1%	0.58	4%	0.06	4%	0.03	4%	0.01

Table 7: Summary of vegetation indexes, for the values used in the logistic regression analyses. The given means are conditional on the indexes being positive.

Similar to the environmental explanatory variables, the vegetation indexes are accumulated backwards in time for 3, 4, 5, 6, 7, 8 and 24 hours, for use in the statistical analysis.
To assess the impact of the use of thickness index, index that replaces the thickness indexes with simple presence of forest or bushes, and their average over similar track sections prior to the position of a registration are also calculated.

Vegetation index that appeared significant from the statistical analysis are shown as a function of the distance to Copenhagen Central Station, for each individual train ride, in Annex H.

2.2.2.2 Construction of indexes for impact of elevation/recess.

Elevation and recess are supposed to impact through their modification of the risk of having leaves on the tracks. Indexes similar to the vegetation indexes are therefore calculated, substituting the thickness index with the height of elevations/depth of recesses in meters. The indexes are summarized in Table 8.

	% positive	Minimum	Mean	Maximum

Elevation	30%	0.0096	3.25	17.55
Recess	21%	0.0004	4.15	28.78

Table 8: Summary of elevation/recess indexes. The given means are conditional on the indexes being positive.

The recess with index more than 28 meters lies just before Vejle.

Index for elevation and recess are shown as a function of the distance to Copenhagen Central Station, for each individual train ride, in Annex H.

2.2.2.3 Accumulated values backwards in time.

The environmental variables listed in Table 4 are all used as explanatory variables directly in the logistic regression analyses, with the exception of WD_10, wind direction in 10 meters height. Furthermore, the accumulated values backwards in time for 3, 4, 5, 6, 7, 8 and 24 hours are also used as explanatory variables. The variables are summarized in Table 9 below, where it is noted that temperature and dew point (T_2,TD_2) are converted from degrees Kelvin to degrees Celcius.

Variable	Present Time	Acc. 3h	Acc. 4h	Acc. 5h	Acc. 6h	Acc. 7h	Acc. 8h	Acc. 24h
PRES	0.14	0.38	0.49	0.57	0.64	0.70	0.73	2.02
T_2	4.73	13.53	17.88	22.27	26.75	31.34	36.03	120.60
TD_2	3.27	9.34	12.37	15.46	18.69	22.05	25.58	88.18
WS_10	5.42	16.05	21.27	26.41	31.47	36.47	41.50	106.03
TKE	1.49	4.35	5.71	7.05	8.34	9.61	10.90	24.85
GLOR	124.1	187.1	187.4	187.4	187.4	187.4	187.4	2868.1

Table 9: Summary of environmental explanatory variables.

The data for environmental variables for individual train rides, immediate and accumulated backwards in time, is depicted as a function of the distance to Copenhagen Central Station in Annex G.

Additional model input.

Curvature is included as an explanatory variable, as described in Section 2.1.5. The curvature is summarized in Table 10 below.

% positive	Min	Mean	Max
32%	0.001	0.56	0.98

Table 10: Summary of curvature. The given mean is conditional on the curvature being positive.

Curvature of the track as a function of the distance to Copenhagen Central Station is shown in Annex H.

The *calendar time* is also included is explanatory variable: A major requirement of t.ex. the vegetation indexes is that there a leaves to blow on the tracks when the wind blows and the vegetation indexes are positive. It would therefore be natural with a leaf index, which, as a function of calendar time, temperature and moisture delivers an expected fraction of the leaves that has been shredded. However, the process of losing the leaves varies from tree type to tree type, and further depends on environmental variables. After consulting with specialists at Section for Forest, Nature and Biomass, University of Copenhagen, it has been concluded that a leaf index is not part of present knowledge and will have to be developed. Such a development project is outside the scope for the current work. However, to account for such an effect, the calendar time from survey start is included as explanatory variable, but in its pure form and in a number of powers; The reason for this is first of all to account any impact outside the included explanatory variables, and second to mimic a sequential part of a leaf index, through interaction with the vegetation indexes. Assuming that the leaf index for the season in 2012 may be thought of as a smooth function of time, this function may be approximated by polynomials in time through Taylor expansion.

Blocking Flag Sequence Indicator is included as an explanatory variable. The point is that as noted, blockings often come in sequences, and due to the much higher number of recordings in IC4 DLU logs, one could suspect that a much larger number of blockings will be registered for IC4 trains, also relative to their larger number of recordings. Indeed, it is clear from Table 6 that the frequency of Blocking Flags is much higher for braking IC4 trains than for braking IC3 trains. This is remedied by introducing a variable that indicates that the current recording is part of a Blocking Flag Sequence, in that *the previous measurement* has a Blocking Flag. This obviously violates the assumption on independence between recordings given the explanatory variables, but it conforms with successive conditional independence, which is a sufficient independence criteria to apply the model described in section 3. Adjusting Table 6 with Blocking Flag sequence, the following Table 11 results:

Train Type	Blocking Flag, non-sequential	No Blocking Flag, non-sequential	Blocking Flag Ratio, non-sequential	Blocking Flag, Sequential	No Blocking Flag, Sequential	Blocking Flag Ratio, Sequential	All
IC3	51	6639	0.77%	56	51	52%	6797
IC4	294	55123	0.53%	2585	294	90%	58296
All	345	61762	0.55%	2641	345	88%	65093

Table 11: Blocking Flags adjusted for Blocking Flag Sequence.

It follows from Table 11 that when blocking sequences are accounted for, the Blocking Flag ratios for IC3 and IC4 trains are comparable. Blocking Flag Sequence introduces a large extra risk, so it is expected that the model impact of the Blocking Flag Sequence will be correspondingly big.

2.3 Summary on data and data quality.

Under ideal circumstances, it is believed that the data types available for this study should be sufficient to perform a thorough analysis with reliable results. However, a number of issues limit the applicability of the conclusions.

A. The low number of GPS data points relative to the large number of DLU data points. Since positions are extracted from the GPS data, this makes estimates of the position, and thus track characteristics, vegetation and environmental variables, crude. The impact of this has not been assessed.

B. The data quality of the speed profiles and braking registrations limits the validity of the results. The speed profiles have more or less all had to be adjusted for time shifts, and while it is believed by the authors that the resulting profiles are close to what should have been recorded, there is no way of knowing it for sure. The large amount of missing data also reduces the overall data material with a large percentage.

C. The data are gathered on a limited number of days. Data from only 11 different days are included in the study, and with so few days, there is a risk that the results will be relative to circumstances for these specific days. In other words, there is a risk that the results may not be generalizable to the whole leaf fall period. Also, it is of course not generalizable to periods outside the leaf fall period.

However, should the above issues be overcome, the authors are of the opinion that the probability of a Blocking Flag may be modeled in the framework presented in section3.

3. Statistical analysis: Inference.

A logistic regression model for the probability of a blocking flag, on the form

$$logit\big(p(Blocking\ Flag)\big) = X^T\beta$$

at any given time and position, where β is a vector of parameters and X an extract of the described explanatory variables and their interactions, is the basic analytical tool that is applied. However, when performing statistical inference, the large number of parameters constitutes a problem. The Inference problem is handled in the following way:

1) An initial model is set up, constituting of all the explanatory variables described in Section 2.2, with calendar time included with a power of up to 5, but excluding variables accumulated over time. An indicator signifying if the train is an IC4 train is also included.

2) 1st order Interactions are included in the model. Quadratic effects of Braking power, Speed and all environmental variables are included. Interactions between IC4 status and quadratic affects are included.

3) The model is reduced at a 5% test level.

4) The following sequence is repeated until no improvement is registered:

a. For all values of lag time, 0, 3-8 and 24 hours, a temporary model is constructed by adding the variables accumulated over the lag time in question, and interactions with track and train ride characteristics. If any variable is present in the model with the same lag time, interactions with this variable are also included.

b. The temporary models are reduced at a 5% level;

c. The Akaike Information is calculated for all 8 temporary models; if the Akaike Information Criteria for any of the 8 temporary models is lower than the Akaike Information for the current model, the current model is substituted with the temporary model having the lowest Akaike Information.

5) When no improvement may be found from the above procedure, the model is reduced at a 1% test level.

The resulting model constitutes the final descriptive model for the data. The fit of this model will be discussed in the results section below.

4. Results.

Coefficients in the final model are presented in Annex D. In the following, the results are summarized, and the impact of each group of explanatory variables is discussed.

First, it should be noted that the coefficients are on the logit scale, which implies that the effect is multiplicative on the odds of a blocking flag (ie., p/(1-p), where p is the probability of a Blocking Flag). Thus, the estimate of the linear predictor $X^T\hat{\beta}$ from the formula in section 3 is not directly translatable as a probability. If a coefficient multiplied with an explanatory variable, that forms a part of the linear predictor $X^T\hat{\beta}$, has the value 1, it means that the effect of the variable is multiplication of the odds for a Blocking Flag with $exp(1) = 2.72$, compared to if the variable was 0. This may turn the probability of a Blocking Flag from close to 0 into something non-ignorable, but if the linear predictor is otherwise very low, it will not change anything at all. In Figure 9 below, the linear predictors cleansed for the effect of Blocking Flag Sequence is drawn, together with the transformation from linear predictor to probability for Blocking Flag. Here, adding 2.72 to the linear predictor may change the odds to a non-ignorable value if the linear predictor is already at a high value, say, -1, but if the linear predictor is at t. ex. -10, a change to -7.28 will not matter the least, when the probability of a Blocking Flag is calculated according to the top most graph in Figure 9.

The probability of a Blocking Flag is much higher than what is depicted in Figure 9, when the blocking flag effect is included. This is discussed in section 4.2 below.

The value of the parameters described below, which all belong to the logit scale, should be viewed in light of this.

Second, it should be emphasized that the probabilities of a initiating a Blocking Flag Sequence, which is what is depicted in the bottom most graph of Figure 9, is only the probability of initiating such a sequence between two measurement points. It therefore cannot be translated into t. ex. the probability of initiating a Blocking Flag sequence during the passage of a certain part of the track, without further elaboration.

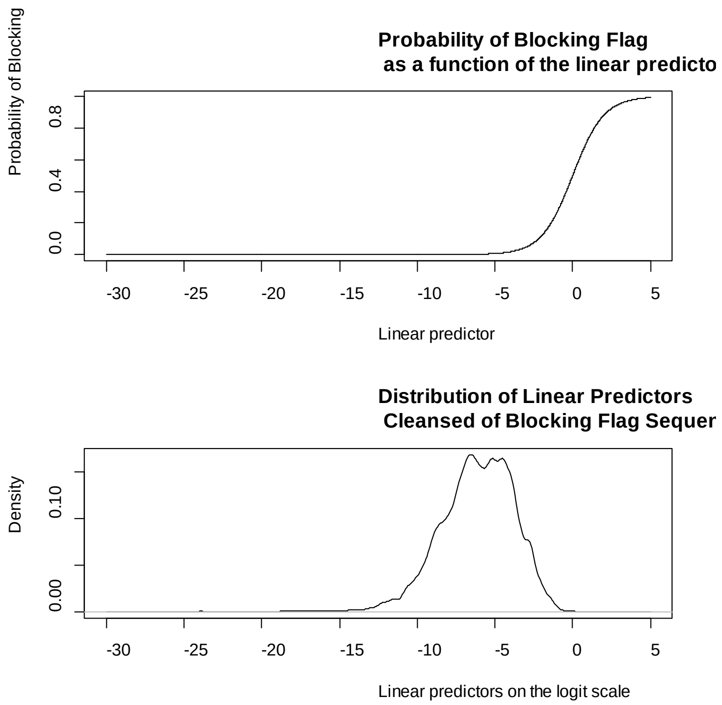

Figure 9: Linear predictors and the probability of initiating a Blocking Flag Sequence.

4.1 Model fit.

In order to investigate the effect of the use of thickness index, the final model was modified to use the indicators for vegetation, elevation and recess, without modifying these with the thickness index. However, the modification resulted in an increase in the Akaike Information of about 63, rendering the model less reliable than the one where thickness index were applied. This justifies the more complicated approach compared to indicators.

Figure 10 shows the temporal correlation of residuals errors from the model fit, after completion of point 4) in the described procedure for the statistical analysis, see section 3. From this figure it follows that all temporal correlation is completely removed, and thus indicates that the model fits the data suitably well at this point. The picture is slightly disturbed after the reduction at a 1% test-level, but this fact represents a necessary compromise between model complexity and fit.

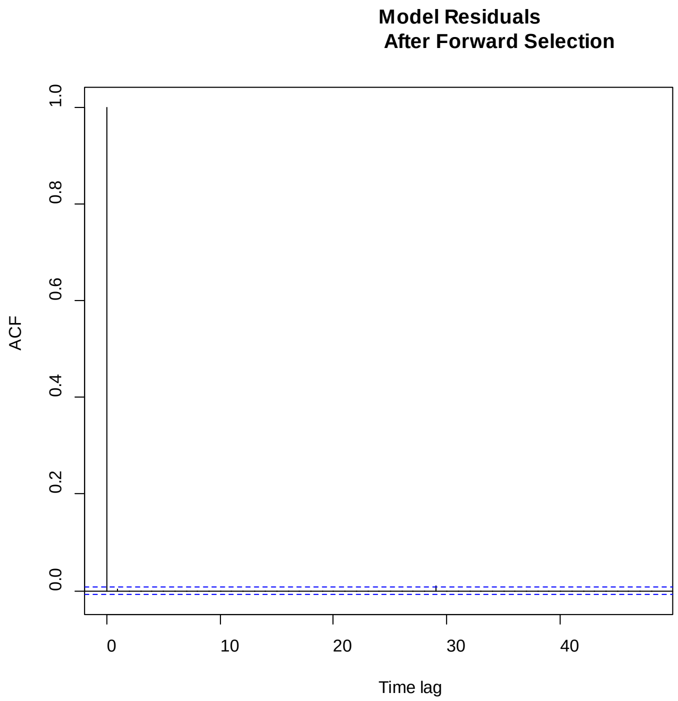

Figure 10: Temporal autocorrelation of model residuals, after forward selection.

4.2 Impact of Blocking Flag Sequence.

As expected, the Blocking Flag Sequence has a large impact. A record in a blocking sequence has the linear predictor increased by 2.721044 compared to a similar record which is not in a Blocking Sequence. This effect increases linearly with calendar time during the survey period, so that at the end of the survey period, the linear predictor is increased with 3.806409 for a record in a blocking flag sequence.

Also, the probability of a Blocking Flag is further increased by 2.373108 if the train in question is an IC4 train. This should be held up against that IC4 trains have much longer blocking flag sequences than IC3 trains, and it therefore cannot be taken as a direct effect of train type, but should be viewed merely as compensator for the long Blocking Flag sequences for IC4 trains.

The effect of leaves from forests is lessened for records in a blocking flag sequence. It is still so that the presence of forest increases the probability of a blocking flag (see section 4.6), but at a much lower rate than for non-blocking flag sequence records, likely a reflection of an already high level of the linear predictor. The impact of adding up to 6 to the linear predictor may be seen from Figure 9.

4.3 Dependency on train type (IC3/IC4).

In general, there is a higher probability of initiating a Blocking Flag for IC4 trains than for IC3 trains. However, the effect is blurred by interactions with a.o. speed and the squared speed of the train, which means that the effect is not obvious at high speeds (here it should be emphasized that IC4 trains were limited to a speed of 140 km/h in the survey period). However, a detailed investigation of the differences between IC3 and IC4 trains is taken up in section 5.2.

IC4 trains are not indicated to be dependent on the immediate humidity in terms of TD_2 as IC3 trains, but a similar amount of risk is instead being put on the immediate temperature T_2. The increasing risk with increasing wind speed is not so pronounced for IC4 trains than for IC3 trains, and the effect of precipitation backwards in time is slightly altered.

4.4 Dependency on train speed.

The effect of speed depends on dew point, train type, vegetation indexes and elevation index.. The relation with dew point is both through the immediate value and accumulated values back in time, and a higher dew point tend to increase the effect of speed. Elevated terrain index tend to decreases the effect of speed, while high speed tend to lessen the effect of forest index and bushes index. The effect for IC3 and IC4 train types is substantially different. For average values of the environmental variables, assuming no presence of leaves nor elevated terrain, the dependence on the logit scale is depicted in Figure 11 below. The apparent decrease in effect for IC4 trains for trains with a speed above 100 km/h is artificial, and a result of modeling date through polynomials of up to 2nd degree. The confidence bands on the figure indicate that it is reasonable to assume that the IC4 effect stabilizes for values of the speed sufficiently high.

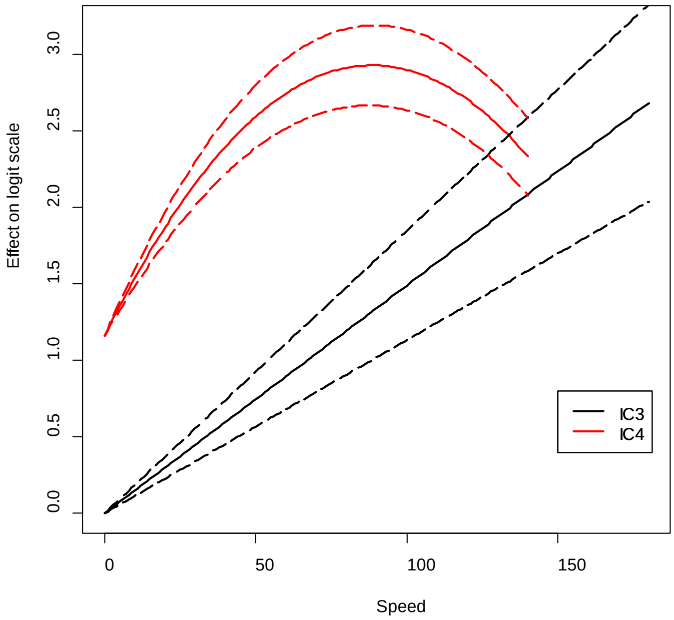

Figure 11: The effect of speed on the linear predictor for initiating a Blocking Flag sequence, for average values of the environmental variable and no effect of leaves or elevated terrain. Dashed lines indicate standard 95% confidence intervals. The estimated difference between IC4 and IC3 trains under average circumstances is added to the effect of IC4 trains.

4.5 Dependency on braking power.

The probability of a Blocking Flag increases with the numerical value of the braking power (the handle position). The effect is altered through the elevation index, the train type and the accumulated dew point. Elevated terrain tend to increase the effect, while high values of accumulated dew point values seem to lessen the effect of hard braking, just as IC4 trains have a slightly lesser effect of hard braking than IC3 trains. The effect of braking power is not indicated to be altered by any vegetation indexes. The effect on the logit scale is nonlinear.

The effect of braking power for average values of environmental variables is depicted in Figure 12. The high level on the 2nd axis should be noted: The effect of hard breaking is substantial. Another notable thing is that the two effect lines for IC3 and IC4 trains intersect each other at a braking power of about 2.35, which is relatively close to the average braking power of trains running at 180 km/h: For trains running between 178-182 km/h when braking is initiated, the average braking power was 2.6.

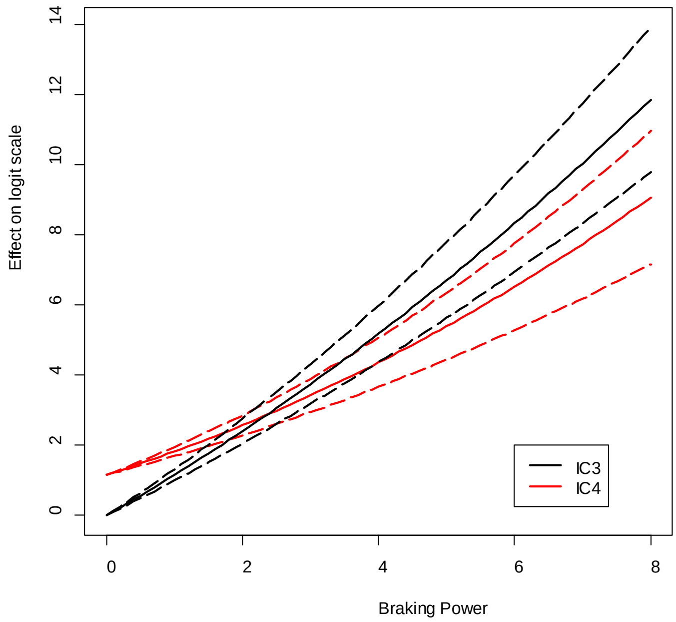

Figure 12: The effect of braking power on the linear predictor fir initiating a Blocking Flag sequence, for average values of the environmental variables. Dashed lines indicate standard 95% confidence intervals.

4.6 Dependency on vegetation and calendar time.

The effects of vegetation and calendar time are linked. Solitaire trees do not have any significant effect on the probability of a Blocking Flag, just as accumulation backwards in time of the vegetation indexes do not result in statistically significant parameters.

The effect of the immediate forest index is a statistically significant increase in the probability of initiating a Blocking Flag sequence. The effect decreases with train speed however, and can no longer be detected at a speed around 140 km/h. The forest index also interacts with the Blocking Flag sequence indicator, lessening the impact of the Blocking Flag sequence with about 0.2 on the logit scale.

Forest impacts through the average index 1 and 2 km back on the track, with a complicated interaction pattern with accumulated values for temperature, dew point, wind speed, solar radiation and calendar time.

Calendar time interacts with wind speed, accumulated values for temperature, and the forest 2km index. The effect of accumulated temperature (over 3 hours) increases with calendar time, while the effect of wind speed decreases over calendar time. The effect on the probability of initiating a Blocking Flag sequence of calendar time, under average environmental conditions (where effects of wind speed and 3 hours accumulated temperature is allowed to develop in a linear way as a function of calendar time), is depicted in Figure 13. Figure 13 illustrates the situation with a forest index of 0, a forest 2km index of 0.064, corresponding to the mean forest 2km index from the data, and finally a forest 2km index of 0.57, corresponding to the maximum forest 2km from the data.. It is seen from Figure 13 that effect of calendar time reaches its peak about 8 days into the study period, after which it declines to a lower level. This development is interpreted as outer circumstances not covered by the environmental data and indexes.

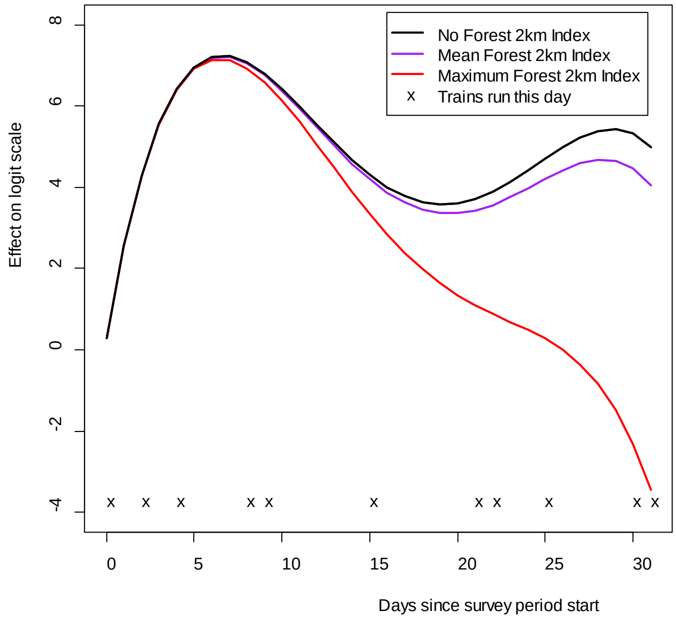

Figure 13: The effects of forest 2km index and calendar time.

The depicted effects matches with the hypothesis put forward that an underlying leaf index is governing the effect of the forest Indexes. When the effect plummets in the end of the survey period for large values of the forest 2km index, an explanation could be that the leaves are simply disappearing, and that there therefore is even less risk when compared to the start of the survey period.

The bushes index increases the probability of initiating a blocking Flag sequence. The bushes index 1 km and 2km back on the track interacts with temperature, dew point and accumulated values of these, mostly resulting in negative effects. Furthermore, the effect increases slightly wit train speed. These effects are opposite of the effect of the forest index, and thus not readily interpretable. One explanation for the effect is that presence of bushes in a longer stretch (and hence 1km and 2km bushes index positive) is a proxy for a specific type of area, where the risk of initiating a blocking sequence when braking is generally low, and thus the effect of bushes index back along the track may effectively be measuring a specific type of terrain. However, such an explanation cannot be examined through the present data and thus remains speculative.

4.7 Dependency on elevations and recess.

A recess increases the probability of a Blocking Flag. The effect of an elevation depends on the wind, the train speed and the braking power. High wind speed over an estimated period of 5 hours tend to increase the effect towards initiating a Blocking Flag sequence, while high train speed and braking power decreases the probability of initiating a blocking flag sequence. In general, elevated terrain decreases the risk of initiating a Blocking Flag sequence, unless the train speed is low and the wind has been blowing iover the last 5 hours.

4.8 Dependency on curvature.

The effect of curvature depends in a complicated manner on wind speed, temperature and dew point. The effect increases with dew point and wind speed, while it decreases with temperature. Overall, the risk of initiating a blocking flag increases with curvature, barring extreme conditions with no moisture, continuing frost, and no wind for several hours.

4.9 Dependency on temperature.

Temperature has a complicated dependence pattern with temperature up to 6 hours back in time impacting on the probability of a Blocking Flag. Temperature interacts with train type, vegetation, calendar time and curvature as described in these respective sections, and furthermore with accumulated values for wind speed and precipitation. However, these effects are small compared to the main effect of present temperature and accumulated values. For average values of the environmental variables, the dependency of temperature backwards in time is depicted in Figure 13.

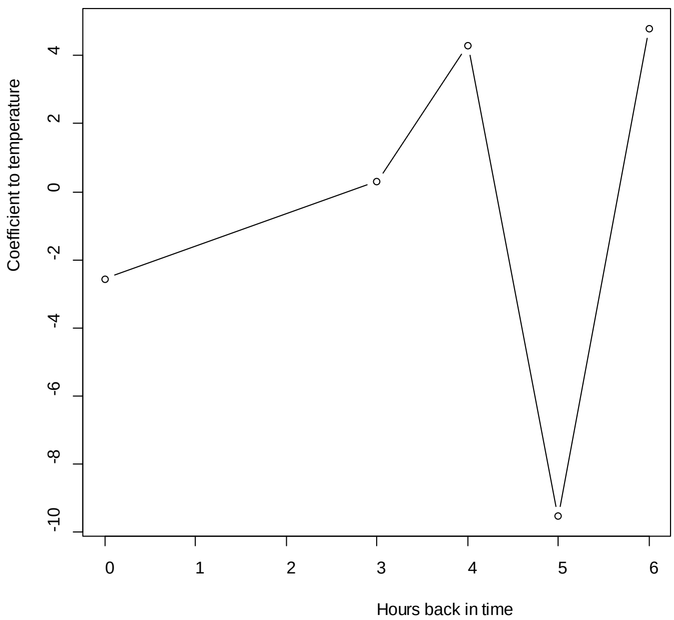

Figure 14: The effect of temperature as a function of time passed, for average environmental effects.

It is readily seen that the risk of initiating a Blocking Flag sequence decreases as the immediate temperature rises. However, while it is also seen that the effects of the temperature 5 and 6 hours back in time more or less outweigh each other, Figure 14 also indicates that artefacts may arise from this estimated structure which therefore do not have a consistent interpretation.

4.10 Dependency on dew point.

Dew point has, as temperature, a complicated dependence pattern, with dew point up to 8 hours back in time impacting on the probability of initiating a Blocking Flag sequence. Dew points interacts with train Type, train speed, braking power vegastation and curvature as described in these respective sections, but in contrast to temperature, dew point doesn't interact with other environmental variables. It is therefore straight forward to construct a dependency graph for the values of dew point back in tiem, which is depicted in Figure 15 below.

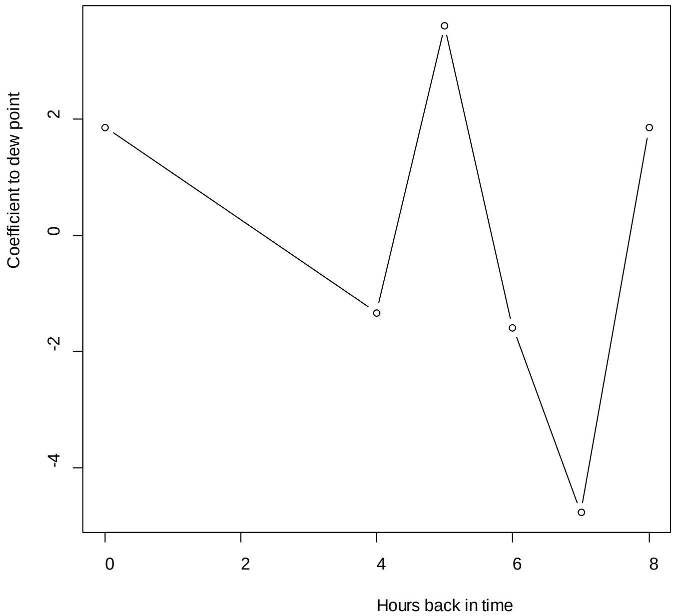

Figure 14: The effect of dew point as a function of time passed, for average effects of train speed and braking power.

4.11 Dependency on precipitation.

In contrast to temperature and dew point, the immediate temperature doesn't have an impact on the probability of initiating a Blocking Flag sequence. However, the cumulated values a long way back in time has an impact, even the accumulated values 24 hours back in time are statistically significant. Precipitation interacts with train type as described in section 4.3. Precipitation also interacts with accumulated values for temperature, wind speed and turbulence, increasing the effect with temperature and decreasing the effect with wind speed and turbulence. The main effect with values back in time lies in the accumulated precipitation over the last 3 hours, which increases the linear predictor for initiating a Blocking Flag sequence substantially, while the effects of accumulated values further back in time have minor impact for average environmental conditions. For precise values, refer to the model parameters listed in Appendix D.

4.12 Dependency on global radiation.

Global radiation interacts with vegetation as described in that section. It also interacts with accumulated values of wind speed with wind speed lowering the effect of global radiation. While Global radiation depends on accumulated values back in time, it is only the most recent 5 hours that has an impact simply because many of the trains do not have much more than 5 hours of daylight behind them when they arrive at Århus. The immediate global radiation tends to increase the probability of initiating a blocking flag. For the precise parameter values, refer to Appendix D.

4.13 Dependency on wind speed.

Wind speed has an impact on the effect of most other describing factors, as demonstrated in nearly all previous sections in chapter 4. In its own right, higher wind speed increases the probability of a Blocking Flag. The effect is pronounced, and consistent back in time for average environmental effects, as depicted in Figure 15 below, where the effect of previous values of wind speed are seen to be slowly discounted.

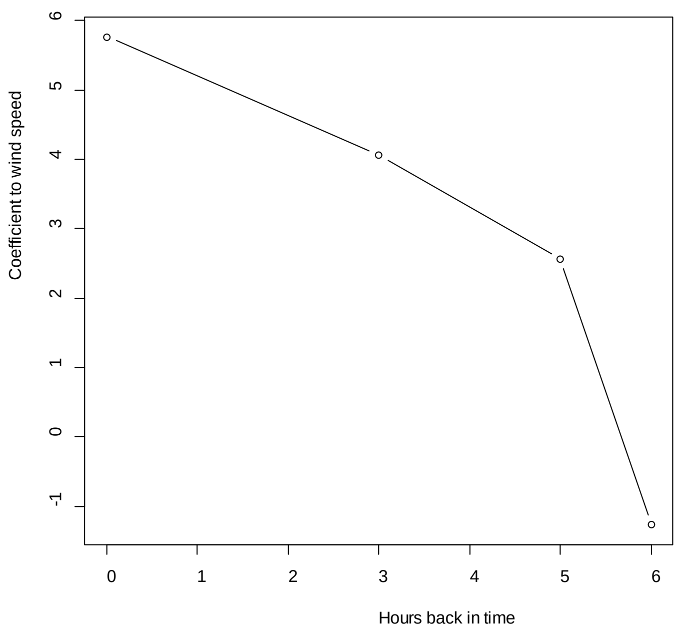

Figure 15: The effect of wind speed as a function of time passed, for average environmental effects.

4.14 Dependency of Turbulent Kinetic Energy.

Turbulence increases the probability of a Blocking Flag. Accumulated values interact with precipitation, reducing the effect as precipitation increases to a minor degree.

5. Discussion and Elaborations.

It has been argued that one might as well study series of brakings instead of the full data. However, a braking typically runs over several kilometers, where the track characteristics, the vegetation and the environmental variables may change. It is not obvious which value of the environmental variables that should be assigned to a braking sequence, and it would also reduce the number of recordings with more than 95%. Attempts have been made to investigate this, but apart from loss of statistical power and a large number of insignificances, the remaining significant parameters were estimated close to the values in the final model, the parameter values as described in Annex D.

It is concluded that the current model has a better utilization of data, and a larger statistical power, and is thus preferable.

5.1 Mapping the risk of initiating a blocking sequence.

The trains from which data are obtained are assumed to act as 'normal' trains, with normal train patterns, braking where trains from Copenhagen to Århus usually brake. As such, the data may be used to construct maps of the risk of a initiating a blocking sequence under a standard train ride from Copenhagen to Århus, based on the part of the track where the trains in the data material has attempted to brake. The data do not contain any direct evaluation of the risk of initiating a blocking sequence in sections where non train has attempted to brake, and therefore the maps following below strictly applies to standard rides, where the braking pattern follows (part of) the braking patterns in the data material.

To utilize this application of the model, the effect of Blocking Flag sequence is subtracted from the linear predictor, and the modified linear predictors are converted to probabilities of initiating blocking sequences, as illustrated in Figure 9, and used to pinpoint areas on the route from Copenhagen to Århus that are at a general risk for initiation Blocking Flag sequences in the considered part of the leaf fall period. It should be noted here again that the data consists on train rides for a limited number of days, but with the reservations for this, the results from the logistic regression model may be applied to construct such indicators. We constructed a smoothed version of such a set of indicators, which are based on predictions solely and not on the actual observed Blocking Flags. The smoothing was first performed for each train ride separately. A window of ± 0.5km was used, together with a Gaussian kernel with a standard deviation of 0.5/1.96 = 0.2551. Then, a second smoothing was performed with the same window and kernel, but where the smoothed values of the 26 used train rides were weighted equally to obtain an estimate for the 'average situation', where high values of the smoothed probabilities indicated a point on the track with high risk in a large amount of the train rides.

Figure 15 below demonstrates how these twice smoothed probabilities distributed themselves along the track line form Copenhagen to Århus.

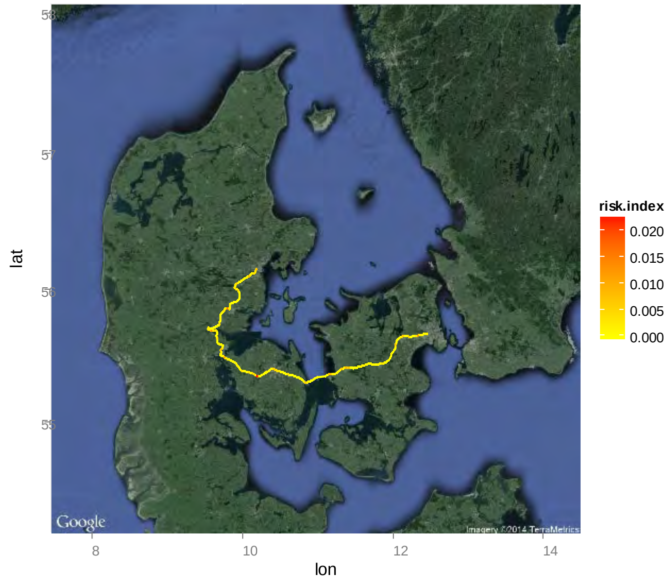

Figure 16: Map of smoothed probabilities for Blocking Flag, Copenhagen-Århus.'risk index' refers relatively to the smoothed probability of initiating a Blocking Flag sequence.

While one is able to detect positions where the red is dominating, it is necessary to magnify the map in Figure 16 to fully comprehend the information. Magnifications of Figure 16 follow in Figures 17-21 below.

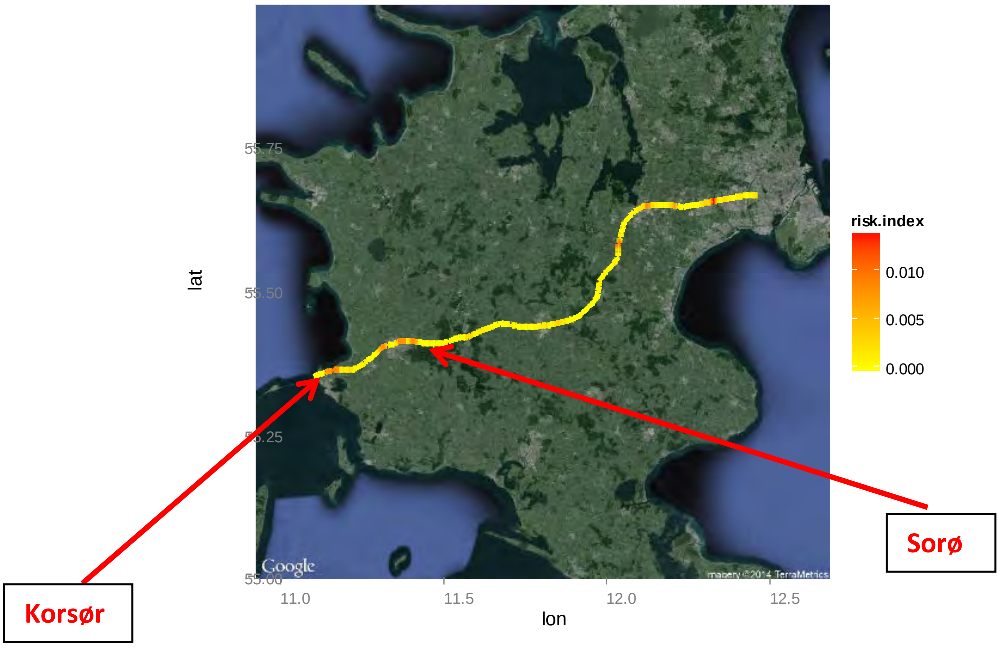

Figure 17: Map of smoothed probabilities for Blocking Flag, Zealand track.

On Figure 17, a red area is apparent just around Sorø. Another red area follows in the forest area west of Sorø. Also, a red area is visible north of Korsør.

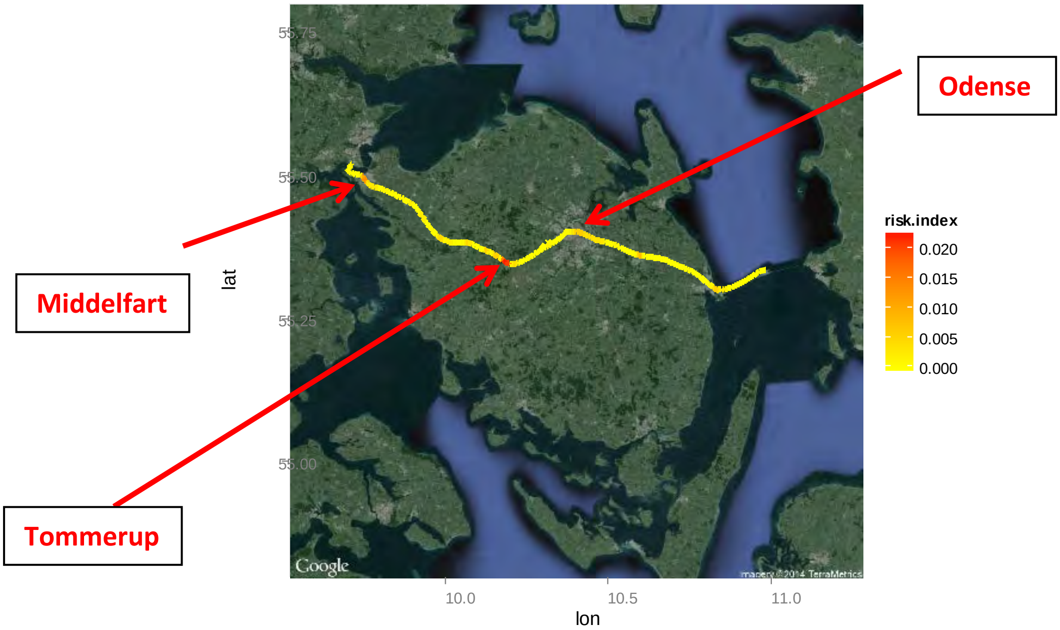

Figure 18: Map of smoothed probabilities for Blocking Flag, Fuenen track.

On Figure 18, red areas are obvious around Tommerup and Middelfart. Note that the scale of the risk index is higher than the scale of the Zealand map.

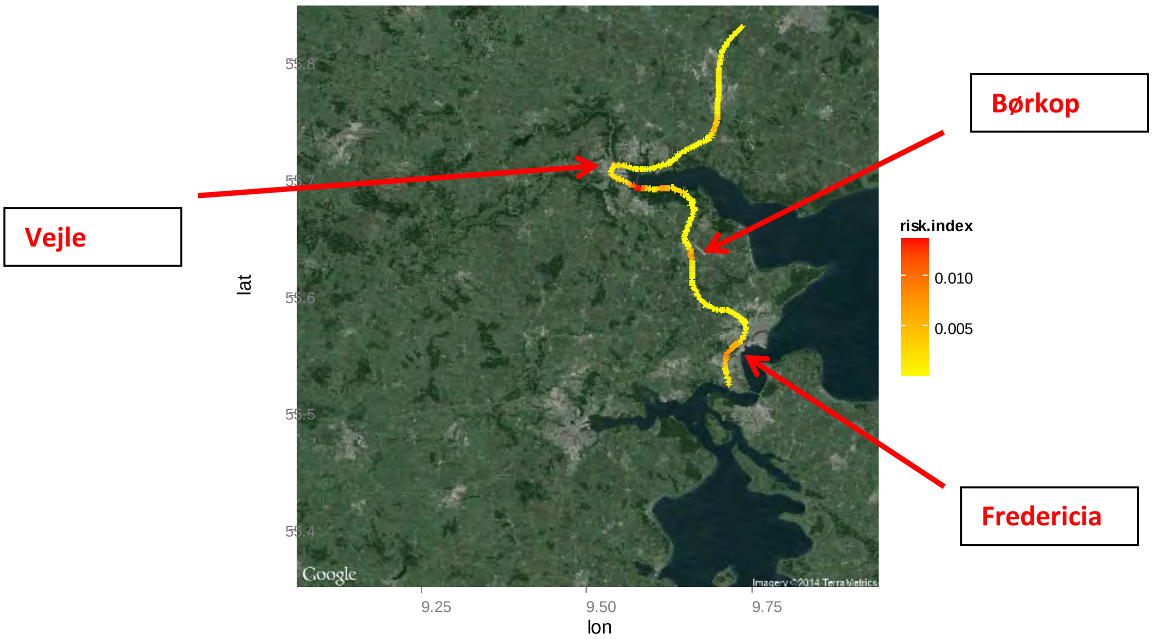

Figure 19: Map of smoothed probabilities for Blocking Flag, Southern Jutland track.

In Figure 19, red areas are visible in Fredericia, but also in Børkop where the track curves a lot, and then in Vejle, after the passing of a large forest area on the left hand side. This fits well with the assumption that leaves causes the track to be slippery, and that leaves from forest 2km back in the track impacts on the risk of a Blocking Flag.

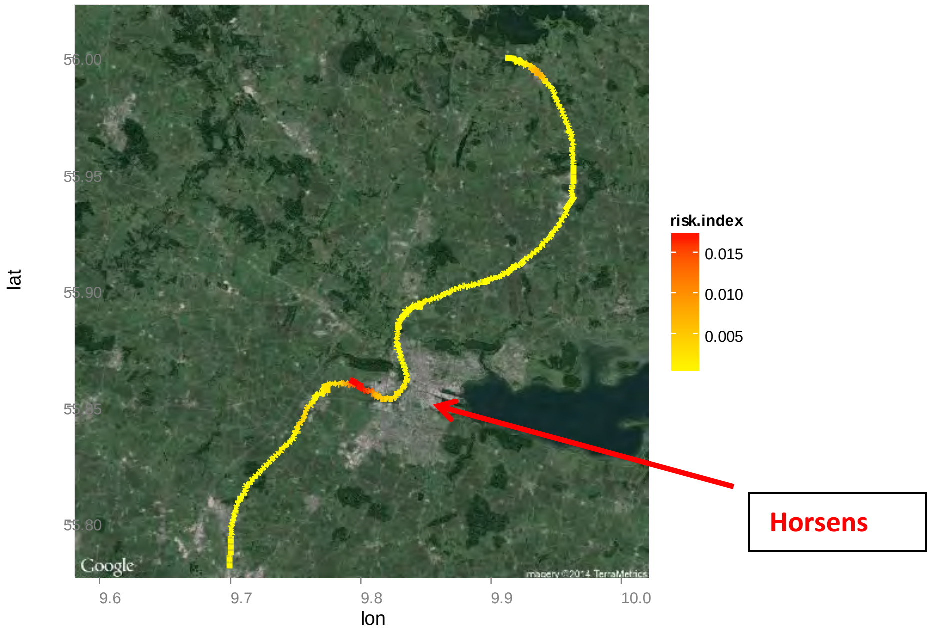

Figure 20: Map of smoothed probabilities for Blocking Flag, Mid Jutland track.

In Figure 20, the train passes a sharp curve of more than 90 degrees just before Horsens, where the train must break. Also, this conforms to the model that rendered curves a risk factor for the probability of a Blocking Flag.

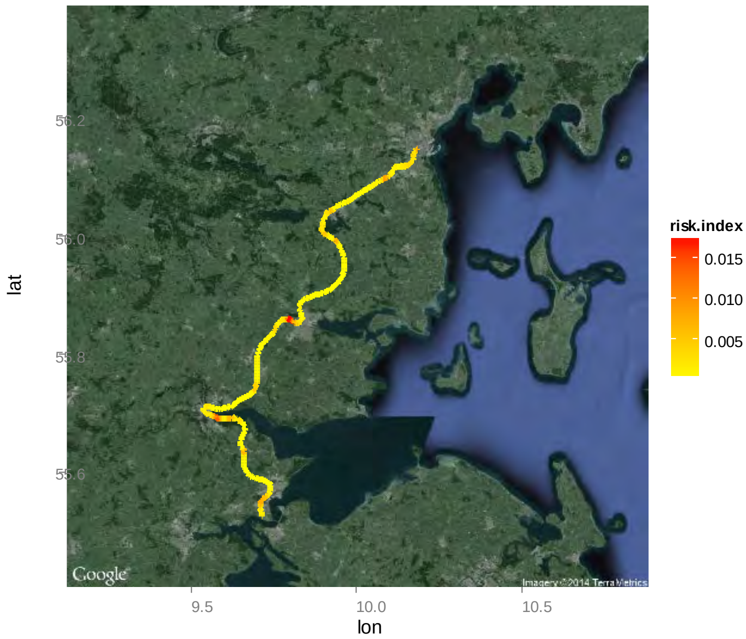

Figure 21: Map of smoothed probabilities for Blocking Flag, All Jutland track.

Figure 21 summarizes Figures 20 and 21 and the remaining route to Århus, and illuminates the difference in risk for the long even stretches where no brakings take place, and thus no risk of Blocking Flag is recorded, giving the color a full yellow.

In Figure 22 below, the smoothed probabilities are depicted as a function of the traveled distance from Copenhagen Central Station. Note that Hjulby, Ullerslev and Marslev lie at traveled distances of 136 km, 141 km and 151 km, respectively. The peaks on the graph should be compared with this. For exact positions of stations on the route in terms of distance from Copenhagen Central Station, see Annex E.

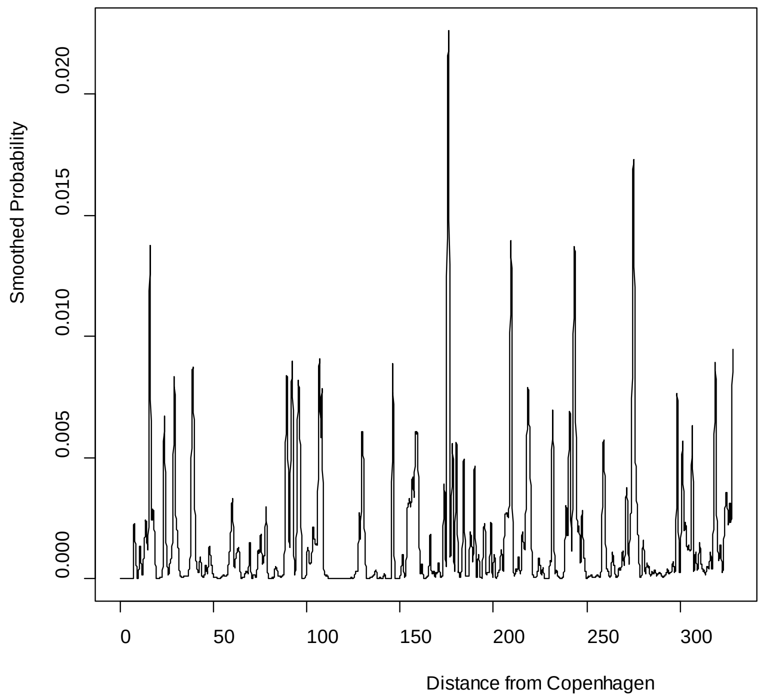

Figure 22: Smoothed probabilities as a function of distance traveled.

5.2 Mapping the risk of initiating a blocking flag sequence anywhere on the route.

A limitation of the analysis in Section 5.1 is that it is limited to the areas where at least one of the 30 train rides has actually resulted in braking. If you do not brake, there is no risk of blocking the wheels, and no reason for considering a Blocking Flag. Thus, the analysis in section 5.1 does not cover the situation where trains brake in unusual geographical positions. However, the developed model is able to predict a probability of obtaining a Blocking Flag, through knowledge of speed, braking power, track characteristics and environmental variables. We used this fact to construct an estimated probability of initiating a Blocking Flag Sequence, for an artificial (IC3) train ride, running at 180 km/h all the way from Copenhagen to Århus, and with a constant braking power of -2.5, corresponding to the average braking power of trains braking at 180 km/h in the data material. We constructed this estimate for all 30 train rides, also those that we did not use for the analysis in section 3, as missing data for speed and braking power is immaterial under this setting. We did not use model predictions for IC4 trains for the speed of 180 km/h, since the model is only tuned to model IC4 trains at a speed of 140 km/h and below.

The technique for constructing the probability estimates was as follows:

a) First, we subtracted the effects of Blocking Flag indicator, train speed, braking power and IC4 status, and all interactions with these, from the current linear predictors.
b) Then, we added effects corresponding to a train speed of 180 km/h, a braking power of -2.5, and corresponding effects of all interactions with train speed and/or braking power.
c) Finally, we converted these modified linear predictors to probabilities of Blocking Flag, through the scheme illustrated in Figure 9.

The resulting probabilities were smoothed in a similar fashion as the probabilities where the actual speed, braking power and train type was utilized. The result for average circumstances, as in section 5.1, together with the result using the actual recorded speed for comparison, is shown in Figure 23 below.

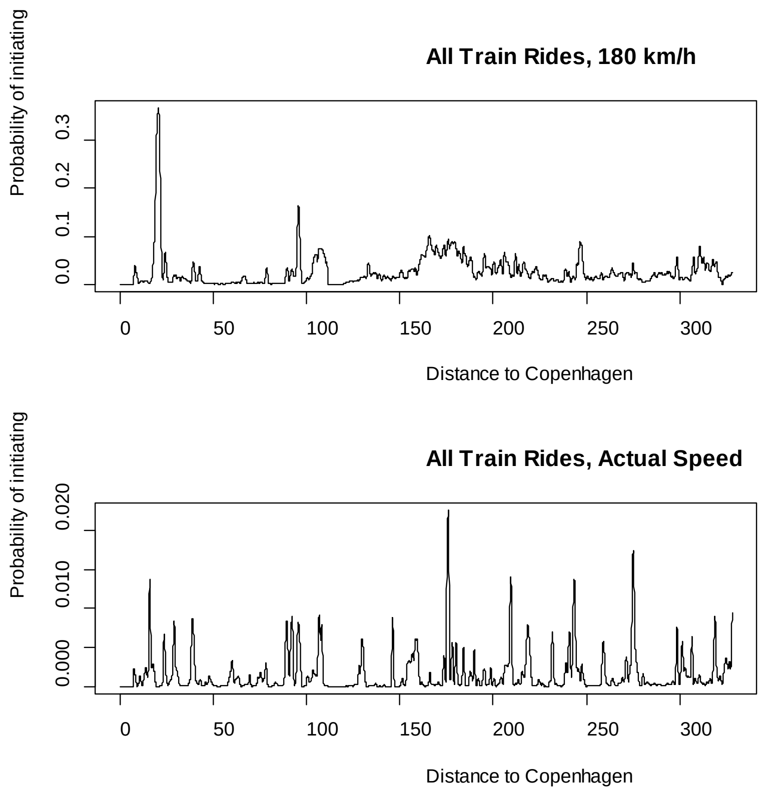

Figure 23: Probability of initiating a Blocking Flag sequence when running at 180 km/h or the actual speed, average circumstances.

The differences in the top and bottom graph in Figure 23 reflects to some extend that not all trains attempted to brake when the average risk was relatively substantial, so that the top graph in Figure 23 has higher values, and also that the higher train speed in general increased the risk of a Blocking Flag sequence (section 4.4). The spikes in the top graph may be identified as the following areas, as a function of distance traveled from Copenhagen Central Station:

19-22 km: The area around Høje Tåstrup Station;
95-96 km: Hyllerup, just after Slagelse;
103-110 km: From Svenstrup prior to Korsør, and on to the Great Belt tunnel;
132-134 km: Shortly after Nyborg Station;
160-186 km: From Odense to Aarup Station;
245-248 km: The area around Vejle Station;
298-299 km: The curving and vegetated area after Hylke, prior to Skanderborg;
306-308 km: The vegetated area after Skanderborg Station and onto Stilling;
318-320 km: The curving area around Kattrup and Hasselager, south of Århus.

However, the ‘average circumstances’ in Figure 23 hides a large variation between train rides. In contrast to the situation where we only estimated the probability of a Blocking Flag sequence when the train was braking, we now have an estimate for every train ride, and every point on the route from Copenhagen to Århus. It is therefore possible to plot a full visualization of the estimates of initiating a blocking Flag sequence for the individual 30 train rides. These may be seen in Annex I together with the graph for average circumstances.
It is noticeable that for a few train rides, the probability of initiating a Blocking Flag sequence is nearly constant 0. This is so for train rides 4 and 7. See Annex F for a description of train type, litra and days traveled for the numbered train rides. A common denominator for these two train rides is that no or nearly no precipitation is found. Conversely, we find from Annex G that the 6 train rides that do exhibit considerable precipitation (train rides 1-3 and 22-24) all exhibit very high probabilities of initiating a Blocking Flag sequence over wide areas. However, the remaining train rides also have examples of such high values. The remaining train rides are not characterized by a particular feature, but do have examples of sunny days, humid days and windy/turbulent days.

The top graph in Figure 23 is visualized geographically in Annex J.

One train ride that may be singled out is train ride number 22, an IC3 train ride on October 29th 2012, a wet, overclouded day with very high wind speed and considerable turbulence. The dew point was considerably lower than average, while the temperature was at the average level. The forest index and the forest index 2km back had values above average and the wind direction was south.

The probability of initiating a Blocking Flag sequence for this train ride is depicted in Figure 24 below:

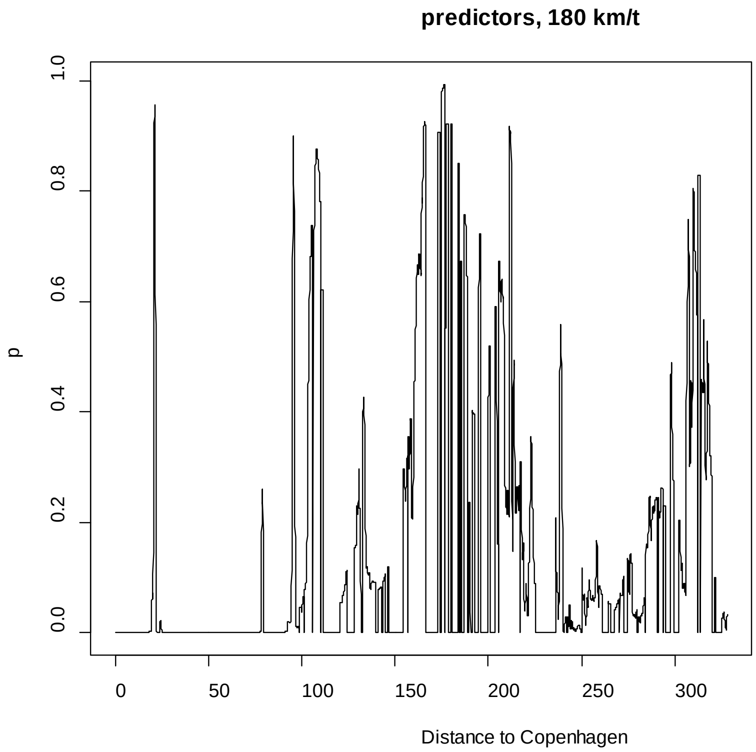

Figure 24: Map of smoothed probabilities for initiating a Blocking Flag sequence, train ride 22, Copenhagen-Århus at 180 km/h.

The first thing to note from Figure 24 is the rather high level of probabilities, after passing Slagelse at 93 km's distance from Copenhagen Central Station. The data are visualized in Figures 25-28 below, using similar map sections as in section 5.1. The second thing to notice is that there is almost no risk prior to passing Slagelse, apart from a narrow peak at Høje tåstrup. By consulting Annex G, it may be noted that this conforms with that the rain on that day starting around the passing of Slagelse. Before Slagelse there was almost no rain, and almost no risk.

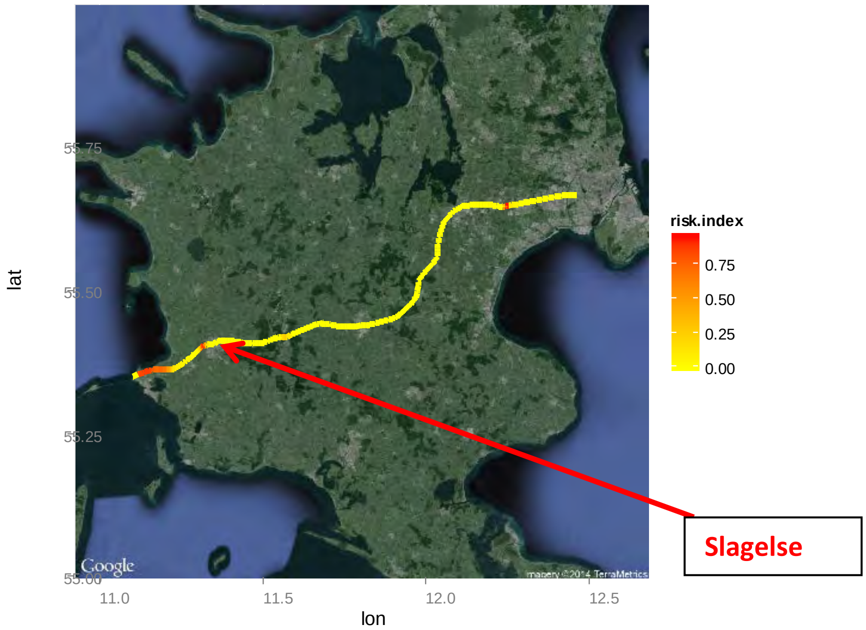

Figure 25: Map of smoothed probabilities for for initiating a Blocking Flag sequence, train ride 22, Zealand track at 180 km/h.

Figure 25 stresses that no noticeable risk is present before Slagelse (barring Høje Tåstrup). After Slagelse however, when the rain starts, areas of high risk appears.

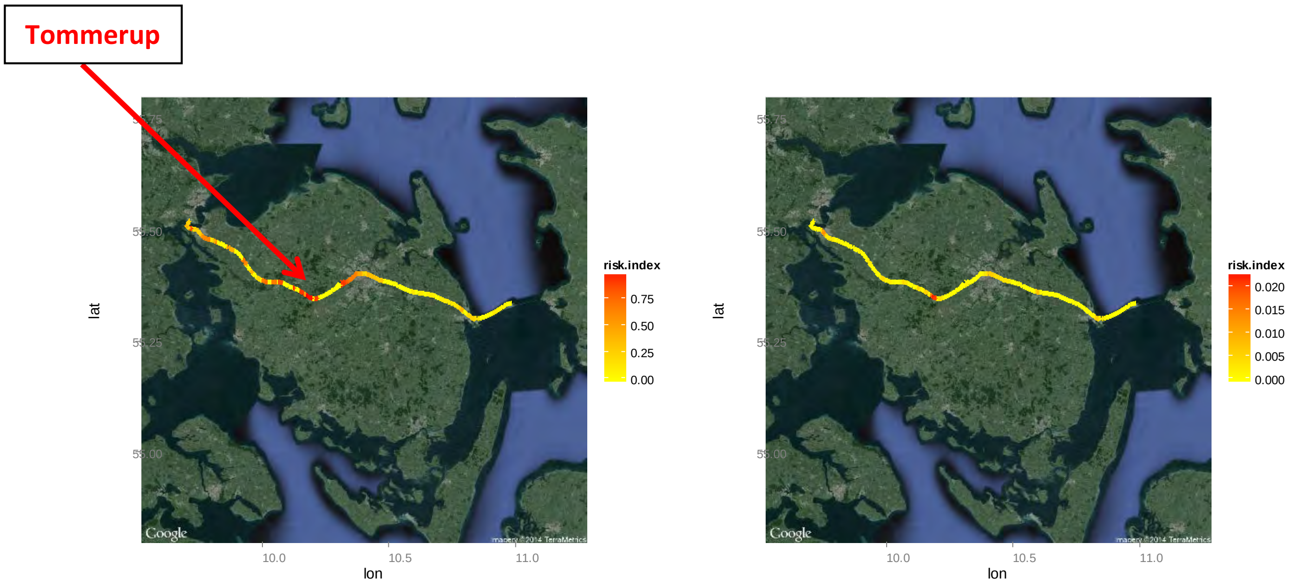

Figure 26: Map of smoothed probabilities for initiating a Blocking Flag sequence, train ride 22, Fuenen track at 180 km/h (left), and similar probability probabilities for the 26 train rides in the leaf fall period for comparison (right, a copy of Figure18).

Figure 26 highlights that the averaged 26 actual train rides, and the artificial train ride with train 22 at a constant speed of 180 km/h may identify completely different areas. The color coding in Figure 27 is not directly comparable between the two subfigures. Never the less, the route from Tommerup to Middelfart is completely yellow on the right side figure, which likely is because that the trains simply don’t break on this route. However, if they did, and circumstances were as on train ride 22, the graph on the left hand side of Figure 26 reveals a significant risk of initiating a Blocking Flag sequence.

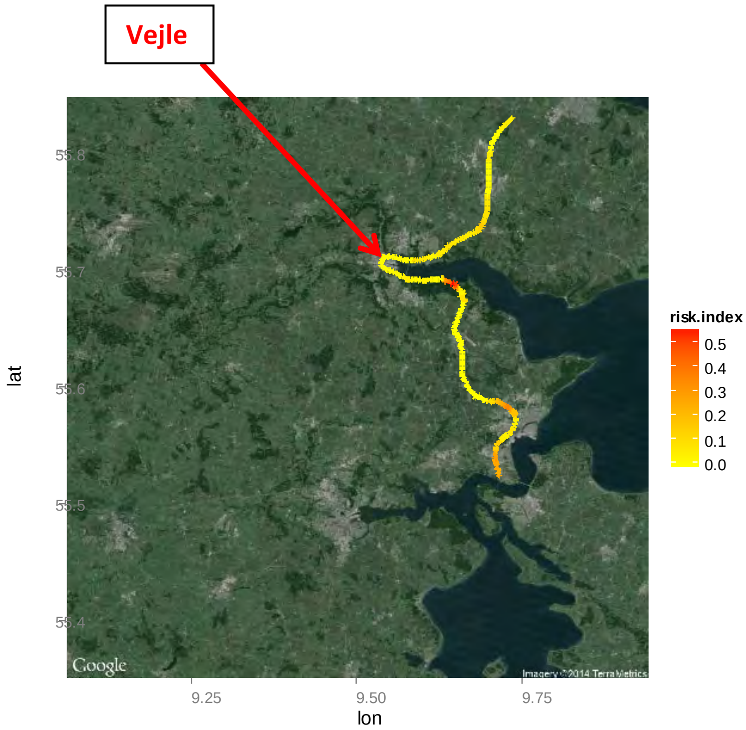

Figure 27: Map of smoothed probabilities for initiating a Blocking Flag sequence, train ride 22, Southern Jutland track at 180 km/h.

In Figure 27, the bright red area occurs prior to both the actual smoothed predictors, and in particular earlier than for the average risks at 180 km/h (see Annex J). It is worth noting that the wind comes from the south (192 degrees, counting right from direction north). Therefore, the left hand side thickness indexes are positive there, and contribute to the red area.

Figure 28: Map of smoothed probabilities for initiating a Blocking Flag sequence, train ride 22, South of Århus track at 180 km/h.

On Figure 28, the red area after Skanderborg coincides with a vegetated area, while there is no immediate explanation for the red area between Stilling and Hørning, but it should be noted that both also train ride 23 and 24 on the same day, and to some extent train rides 2 and 3 that occurred 4 days later, exhibit increasing probabilities of initiating a Blocking Flag sequence in this area, as does the average risk profile. These 5 train rides contains both IC3 and IC4 train rides.

Another train ride that may be singled out is train ride 17. In contrast to train ride 22, train ride 17 occurred on a completely dry day, November 23rd, 2012. The weather was windy and turbulent, and it had been windy and turbulent for several hours prior to train ride 17 (see Annex G). Thus, the environmental conditions were completely different from Train ride 22. Yet, as seen in figure 29, a high risk of initiating a blocking Flag sequence occurs around the start of the great belt tunnel, and in several areas on Fuenen and in Jutland.

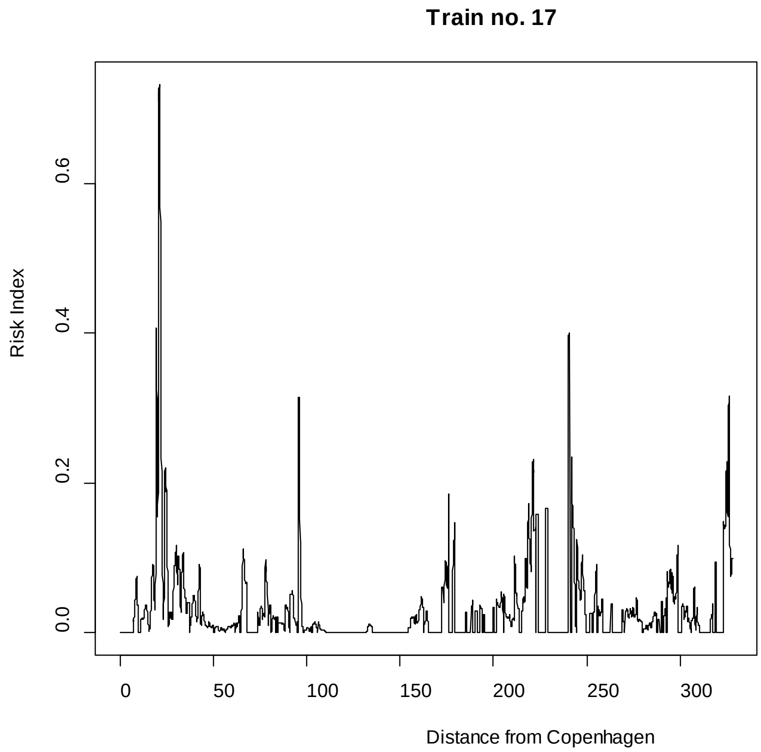

Figure 29: Probability of initiating a Blocking Flag sequence when running at 180 km/h or the actual speed, train ride 17.

Thus, Figure 29 suggests that there are many ways that slippery tracks may be obtained, and in particular that precipitation is not the only way to obtain slippery tracks, since no precipitation had occurred in the last 24 hours prior to train ride 17.

5.3 Comparing IC3 and IC4 Trains.

It is not possible to use the predictors obtained for running at 180 km/h for comparing IC3 and IC4 trains, because the IC4 trains have only been running 140 km/h in the survey period. However, one can construct predictors completely similar to the 180 km/h case, where the trains run at 140 km/h with a fixed braking power. In this situation it is possible to compare the predictors for initiating a Blocking Flag sequence for IC3 and IC4. This has been performed using a fixed braking power of 3.4 instead of 2.6, corresponding to the average observed braking power at 138-142 km/h. The obtained linear predictors were transformed into probabilities for initiating a Blocking Flag sequence in the way illustrated in Figure 9. This way, all bias from environmental variables and track properties are (close to) eliminated for the comparison, as the two train runs are performed under exactly the same conditions.

The two obtained distributions of probabilities of initiating a Blocking Flag sequence are compared in a quantile-quantile plot in Figure 30 below.

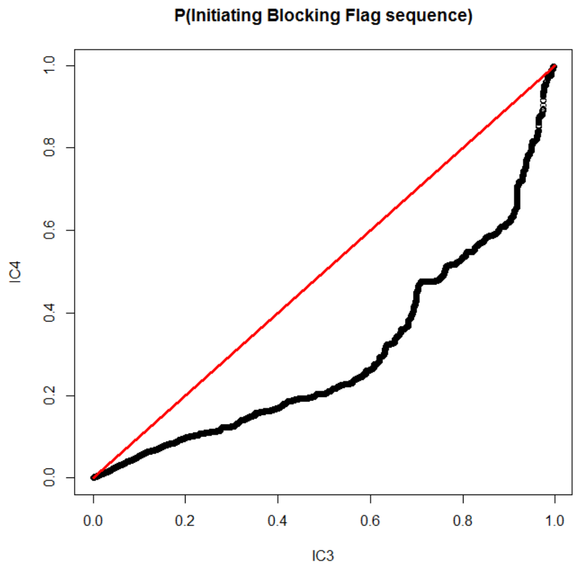

Figure 30: QQ-plot of probabilities for IC3 and IC4 trains, respectively, with the red line representing identity.

Figure 30 show that t. ex. the value corresponding to the lowest 40% of the IC3 probabilities, only matches about 18% of the IC4 probabilities. In other words, since the black curve is consistently below the red line of identity in Figure 30, we may conclude that the IC4 probabilities are bigger, and thus the IC4 trains have a higher risk of initiating a Blocking Flag sequence than IC3 trains.

A Kolmogorov-Smirnov test for this comparison is also strongly significant.

One should take note on, first of all, that this conclusion is based on data which to some extent have been reconstructed, and which are only based on a minor number of observational days. Furthermore, it should be emphasized that the conclusion relates to the probability of initiating a Blocking Flag, which we cannot translate directly into low adhesion. It has not been possible to obtain precise criteria for when IC3 and IC4 trains raise a Blocking Flag, and if the IC4 trains electronic systems are more sensitive than the IC3 trains, we may simple have shown such an effect which would be completely irrelevant for differences in low adhesion. However, one factor that speaks against interpretation is the interaction of train type (IC3/IC4) with train speed, see section 4.4.

6. Conclusion.

The modeling work has identified a proper model for the data, just as the model have been expanded to an early warning type model that applies to the whole track from Copenhagen to Århus. The answers to the initial questions that this report was concerned with, appears from sections 4.6 and 5.3. While the modeling work suggests that the model can be generalized to the whole leaf fall period and beyond, and to all tracks in Denmark, the current analysis is based on too many approximations to render the results trustworthy. It is a hindrance for the analysis that we been unable to work with a measure of the adhesion. However, because of reservations as in section 2.2.3, a more thorough data base, and perhaps the development of a leaf index, would greatly solidify the results, which need not be incorrect but lack the statistical foundations to be trusted.

Technical University of Denmark,

February 21st, 2014.

Overview of Annexes

<u>Annex A</u>: DLU log description, IC3. 3 pages.

<u>Annex B</u>: DLU log description, IC4. 31 pages.

<u>Annex C</u>: Extract from Curve Registry user manual (in Danish). 2 pages.

<u>Annex D</u>: Coefficients in final model. 3 pages.

<u>Annex E</u>: Distances to Copenhagen Central Station for reference stations. 1 page.

<u>Annex F</u>: Relations between train numbers used in Annexes G-H, and litra, calendar day and train type. 1 page.

<u>Annex G</u>: Environmental data along the train routes, immediate and accumulated backwards in time. 241 pages.

<u>Annex H</u>: Curvature of the track, and statistically significant indexes related to wind direction, along the train routes. 61 pages.

<u>Annex I</u>: The probability of initiating a Blocking Flag sequence at 180 km/h as a function of distance to Copenhagen Central Station, individual train rides and weighted together. 31 pages.

Annex J: The probability of initiating a Blocking Flag sequence at 180 km/h as a function of distance to Copenhagen Central Station, weighted together and visualized in geographical maps. 6 pages.

2.0. Beschreibung der Datenaufzeichnung

2.1 Analogwert-Aufzeichnung

Zur genauen Rekonstruktion des Fahrverlaufes für die zuletzt gefahrene Wegstrecke werden alle wichtigen Fahrdaten unkomprimiert im Unfallspeicher abgelegt. Von der Meßanlage wird geschwindigkeitsabhängig ein Istwerttelegramm im folgenden Wegraster an die DSK10 gesendet:
(Aufbau siehe Anhang A. Das Wegraster entspricht dem des Unfallspeichers)

	<60 km/h	**5 m Wegabschnitte**
_ 60 km/h bis	**<120 km/h**	**10 m Wegabschnitte**
_120 km/h bis	**V-max.**	**20 m Wegabschnitte**

Wenn innerhalb eines Wegabschnittes handelser. Ereignisse wie Zusatzinformationen (binäre Signale), Baliseninformationen oder ATC-Fehler auftreten, werden diese foran vor dem Istwerttelegramm an die DSK10 gesendet und auch in gleicher Reihenfolge im Speicher abgelegt. Dadurch kann das oben genannte Wegraster nicht immer eingehalten werden. Die Meßanlage addiert die Weglänge, die während des Telegrammverkehrs gefahren wurde und sendet das Istwerttelegramm z.B. statt nach 10 m erst nach 15 m.

Im Istwerttelegramm sind außer der gemessenen Geschwindigkeit (V_Ist2) noch vier weitere Analogwerte enthalten.

2.2 Zusatzregistrierungen

Die Meßanlage sammelt alle Änderungen der Zusatzinformationen, bis ein Wegabschnitt von 5m beendet ist und sendet diese Informationen mit dem aktuellen Weg seit Beginn eines Wegabschnittes an die DSK10.
Es werden 16 Zusatzinformationen (Einzel-Bitinformationen) unter medgivelse Beigabe von Weg, Minuten und Sekunden registriert. Die Minuten und Sekunden refererer beziehen sich auf die Zeit der Speicherung. Da bei Stillstand **keine** Speicherung erfolgt, sondern erst nach Fahrtbeginn , wird in diesem Fall **nicht** die Zeit des Auftretens registriert.

2.3 Sonstige Aufzeichnungen

Im Stillstand, wenn die Meßanlage eingeschaltet ist und alle 2 Sekunden ein Kontrolltelegramm mit der DSK austauscht, registriert die DSK10 bei jedem Tageswechsel einen Datensatz mit Tag, Monat und Jahr, bei jedem Stundenwechsel einen Datensatz mit Uhrzeit. Wenn das Fahrzeug anfährt und der 1.Wegabschnitt beendet wurde, sendet die Meßanlage nur dann ein Telegramm mit **Kopfdaten**, wenn es der 1. Wegabschnitt nach dem Einschalten der Anlage war oder wenn die Kopfdaten (im Stillstand) geändert wurden. Die DSK10 registriert die Kopfdaten mit Datum und Zeit und hält wie bei jedem Fahrtbeginn das Ereignis durch die Kennung "Fahrtbeginn" fest.
Wenn während der Fahrt ein Stunden-oder Tageswechsel stattfand, wird Wegsynchron eine "Zeitmakierung" und "Datumsmakierung" vor der Istwertregistrierung aufgezeichnet. aufgezeichnet.
Nachdem ein Istwerttelegramm mit der Geschwindigkeit V_Ist2 = 0km/h gesendet wurde, erkennt die DSK10 das Ende einer Fahrt nur dann, wenn zuvor V_Ist2 größer 0km/h war. Dann wird die Kennung "Fahrtende" vor der Istwertregistrierung aufgezeichnet. Werden im Stillstand noch weitere Istwerttelegramme mit der Geschwindigkeit 0km/h gesendet, bedeutet das, daß ein Wegabschnitt von 5 m mit sehr geringer Geschwindigkeit durchfahren wurde (Schleichfahrt) .

Baliseninformationen und **ATC-Fehler** werden nach dem Eintreffen in der DSK10 mit Minuten und Sekunden zu Beginn des aktuellen Wegabschnittes aufgezeichnet.

2.4 Prinzip der Aufzeichnung

Zur leichten Identifizierung der aufgezeichneten Daten beginnt jeder **Kenndatensatz** mit der Kennung FF Hex, gefolgt von einem Kennbyte 0..6. Das Kennbyte wird durch die oberen 3 Bit (Bit 5..7) dargestellt. Die unteren 5 Bit sind reserviert für Weginformationen.
Vom Prinzip der Aufzeichnung her darf ein 8-Bit Analogwert nicht größer als 254 werden!

2.5 Betriebsspeicher

Das Verfahren der Datenkompression wird gegenüber der Version N verbessert:

Die Datensätze 0 (Analog), 1 (Kontakte) und 5 (ATC-Fehler) erhalten im Betriebsspeicher (nicht im Unfallspeicher) ein zusätzliches Byte für die Weg-Information. Der Weg wird immer mit einer Auflösung von 5m gespeichert. Da jetzt 8 + 5 = 13 Bit zur Verfügung stehen, kann ein Weg von maximal 2^13 * 5m = 40.000 m zusammengefasst werden, solange alle Analog-Werte konstant sind.

Die Änderung eines Analogwertes wird erkannt, wenn der Wert, der von der MA10 empfangen wurde, sich um eine vorgegebene Toleranz (+ oder -) gegenüber dem zuletzt im Betriebsspeicher abgelegten Wert ändert. Nach einem Reset wird mit 0 verglichen.

Toleranzen:	V-HLOG	4 km/h	
	V-Ist-ATC	4 km/h	
	V-Überwachung	4 km/h	
	Zug- Bremskraft	3 Digits	bei Litra-Gruppe EA
		1 Digit	sonst
	Bremsdruck	5 Digits ^= 0,5 bar	

Folgende Sonderfälle können Auftreten:

1. Die gesammelte Wegstrecke ist < 50 m:
   Die Datenkompression wird nicht abgebrochen, selbst wenn sich ein Analog-Wert ändert.
   Dadurch soll ein zu schnelles Füllen des Betriebsspeichers verhindert werden.
2. Die gesammelte Wegstrecke ist 40000 m (^= 8000 Wegeinheiten):
   Die Datenkompression wird in jedem Fall abgebrochen, damit der Wegzähler nicht
   überläuft.
3. DSK10 erkennt Fahrtende:
   Die Datenkompression wird abgebrochen, bevor der DS 2.2 geschrieben wird, damit bei
   einem möglichen Auslesen der Daten im Stillstand der Weg vollständig abgelegt ist.
4. Stunde wechselt, Tag wechselt:
   Die Datenkompression wird abgebrochen, bevor DS 2.0 oder DS 2.1 geschrieben werden.
   Die Zeitinformation in DS 0 ist die Zeit vor dem Wechsel.
5. DSK10 erhält Kontaktwechsel:
   Die Datenkompression wird nicht abgebrochen. Der entsprechende Datensatz wird in den
   Betriebsspeicher geschrieben. Der Weg in diesem DS ist der relative Weg zum letzten DS 0
   Analog) im Betriebsspeicher.
6. DSK10 wird ausgeschaltet oder Reset tritt auf, während die Kompression läuft:
   Der bis dahin gesammelte Weg geht verloren.
7. DSK10 erhält ATC-Fehler:
   Die Datenkompression wird abgebrochen. Der entsprechende Datensatz wird in den
   Betriebsspeicher geschrieben. Der Weg in diesem DS ist = 0.

2.6 Speicherung der Balisen

Die Balisen werden im Unfallspeicher mit Weg, Minute und Sekunde. Zusätzlich werden die jeweils letzten 5 Balisen in einem Ring-Puffer gespeichert. Jede Balise wird mit Datum und Uhrzeit, aber ohne Weg, abgelegt. Wenn eine ATC-Fehler-Information kommt, werden die Balisen in den Betriebsspeicher **vor den ATC-Fehler** kopiert. Falls seit dem letzten ATC-Fehler weniger als 5 Balisen empfangen wurden, werden nur die neu hinzugekommenen gespeichert.

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Specification No.: **PH251**

Contents: **EFA21a recorder (DLU)**

Customer: **Ansaldobreda**

Project: **DLU for IC4, DSB**

Basis: **DMU IC4 Technical Specification for Train Data Recorder Rev. 0**

VEK **1960**

File PH251_DLU_IC4_A.doc

Version	Date	Pages	Changes
H	15.04.03	30	Initial version (based on the document "DLU_Systemdescription_G.doc")

Version	Originated by	Checked by	Release DEUTA-WERKE	Release Customer
H	Miehlbradt	Wasser		

ANSALDOBREDA
AA 02 RW5
P/N REV: H
TAV. / SHEET:

CONTENTS

Amendment journal (History of the document)

Edition	Date	Place	Changes	References
A	10.07.02		Initial version (System description of the delivered functional prototyp)	
B	20.09.02	2 4.2.1.1 5.7.1 5.8	Extended version (⇨ using a goldcap instead of a LI battery for the RTC)	Meeting in Pistoia KW37 / 02
C	04.11.02	4.2.1.2 / 5.7.4	No monitoring of the current of the signal lamps	Meeting in Pistoia KW37 / 02 and Comments from DSB and Email from Mr Nesti, 28.11.02
		5.1.1 5.1.3.2	Signal definitions	
		5.5	Start- / Stop record	
		5.7.1	DSK21 errors updated	
		5.9 / 6	Codeplug for train ID	
D	14.01.03	5.1.1	New Signals 13a – 13d; 29	Email from Mr Nesti, 04.12.02
		5.1.3	New Signals Sp104 – Sp109	
		5.3	logging of the brake force HD1 / 4 retarder	
		5.8	Time synchronisation	
		4.1.1	Figure	
E	22.01.03	5.1.2.1	New signals ZWG20_1_ATC_Main_Switch also in this point: LokNbConnectorActiv	(Corrections only)
		5.1.3	New MVB-ports : 1110, 1120, 1130, 1140 life counter : CycleS3 – CycleS6	
		5.5	Startrecord : v>=2km/h ; Stoprecord : v<=1km/h	
F (no longer draft version!)	03.02.03	4.3	NUP-T2	see based document: DLU_Systemdescription_draft_E_rev_03_02_03.doc
		5.1.1	MVB IDs according to DMU IC4 DLU Bus Data Flow, Mod 2 Sp34: Signal name	
		5.1.3.1	Sp40 = INTEGER8 Sp110 – Sp119 = MVB_ccu_o_pfa1 to MVB_ccu_o_pfa10	
G	01.04.03	4.1.1	two special screws for sealing the DSK21 module	
		4.2.4.3	Text deleted	
		5.1.2	Logging of ZWG20-signals (Sp72, Sp73)	
		4.2.2 5.1.3.2	train ID number input only via codeplug	
		5.1.4.1	Correction: ATC-Telegr. c :'S':'OFF'; 'T':'ON' Handling of an ATC telegram with unvalid data	
		5.1.4.2	Note: Telegram 'N'	
		5.2	Recording the ATC telegram SPAD in crash2	
		5.3	List of all recorded analogue values (deviations)	
		5.5.3 and 5.1.1	StartStop – Signal	
		5.6	point 14. added	
		5.7.4	messages that affect the signal lamps updated	Email from DSB Apr. 01st 03
		5.8	Time synchronisation: Additions and corrections	
		any	Corrections and additions	
H	15.04.03	none	Changed to specification document "PH251_DLU_IC4_H.doc". This document replaces the two documents "PH251_GB_B_Part1_HW_D.doc" and "PH251_GB_B_Part2_SW_D.doc"	

		5.7.1	„ATC_not_obtainable“ removed from „DSK21_Errors“	DSB_Comments to ph251-g250303.doc
		5.5.1	Recording in crash memory	

1 General

The EFA21 System comprises several individual components linked through an ICOM serial interface. This is a 4-wire bus with a transfer rate of 375 kbaud with signal levels as per RS485.

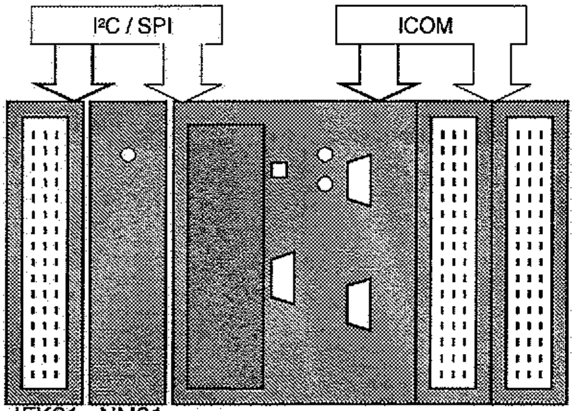
The master in the system is the DSK21 (with vehicle-bus interface). For measurement-recording functions special slaves can be used (ZWG20, GPS20 etc).

2 Purpose of this document

This document describes the EFA21a for use as a Data Logging Unit (DLU) with DSB.
If there were any outstanding points in the requirements, the functions which will actually be implemented are described here.

3 Short description of the individual modules

3.1 Basic structure



The **EFA21a** system is based on the data-storage module of the **DSK21** with MVB card in conjunction with a central distance- and speed-recording module **ZWG20**.
The ATC for the DSB transmits data through a 20mA interface.
The DSK21 records travel data from the ATC, MVB and ZWG20 module.

Module	Function	Inputs	Outputs
IFK21 connection adapter with an M multiple pin strip on the front panel	Power line filter and connections from the backplane, RTC	Power supply, ATC-20mA interface	2 outputs for signal lamps in driver cab, SPI for optional PMS
NM21	Power supply for all EFA21a modules	24VDC – 110VDC	All voltages required by the EFA21a modules
DSK21	Master, recording data from MVB,.ATC interface and ICOM interface	MVB, ATC bus, ZWG20 signals (ICOM),service interface	Data storage (PCMCIA- / SPI- Interface), I²C, status LED
ZWG20	Basic and expansion card Type 1	16 optocouplers (DI)	6 relays
		2 frequency inputs	2 frequency outputs
		2 analogue inputs	2 analogue outputs

3.2 NM21 Power-supply

Power is supplied by the NM21 Power Pack.

For further hardware description see
"Instruction Handbook NM21" (4AB825GB).

3.3 DSK21

For further hardware description see
"Instruction Handbook DSK21 Data Storage Cassette" (4AB816GB)

3.3.1 General

The DSK21 is the central control unit in the EFA21a DLU. The DSK21 receives data serially from the ATC through a 20mA power interface, through MVB an interface and also through the internal ICOM interface from the ZWG20 module.
The EFA21a can be configured through a serial RS232 service interface, through which status information etc. can also be retrieved from a PC with the appropriate service software.

3.3.2 Interfaces

- MVB interface, class 1.3
- ATC interface, 20mA, passive, 1200 baud
- ICOM interface, RS485, 375 k baud
- Service interface, RS232, 9600 baud
- I²C – Interface (for reading out the train identification data of the I²C-EEPROM on the backplane board and controlling the outputs for the signal lamps in the drivers' cabins).

3.3.2.1 MVB interface

The DSK21 receives the data from the MVB through a DUAGON PC/104 MVB card (2 front-mounted Sub-D terminals), processing the process data as it is received.
Configuration is effected using PV-Names and NSDB files based on the MVB-specification between DEUTA and Ansaldobreda.

3.3.2.2 ICOM interface

The RS485 interface to each station for connecting the DSK21 to the ZWG20 module is of an electrically isolated type.
baud rate: 375 kbit/s

3.3.2.3 Service interface

An RS232 service interface to BN411004 has been implemented on the DSK21. With this interface it is possible to read information from the system and to configure the system.
The ZWG20 module has no service interface of its own. All necessary settings (configuration, wheel diameter for measuring speed and distance,...) are effected at the DSK21's service interface and relayed to the ZWG20 module through the ICOM interface.
There is no provision in the operating software for reading out the stored travel data through the service interface, since with a memory configuration of 4 MB or more the transfer time would be unacceptably long. (The PC-Card, that is read out with ADS3 software can be used in the DSK21 furthermore without new preformatting or an other, special action.)
A description of how to load new operating software into the DSK21 can be found in the *"Instruction Handbook for the DSK21 Data Storage Cassette"*.

For further software description see
"Manual Service Software" (4AB849GB).

3.3.2.4 Serial 20mA interfaces (ATC)

The DSK21 and ATC are connected through the passive, serial 20mA interfaces.

- baud rate,... 1200 bit/s, 8 data bits, odd parity, 1 stop bit

The DSK21 extracts the signals to be archived in the data store from the serial data.
Protocol version 3. 01.11.98 is used.

3.3.2.5 I²C Interface

The I²C interface of the DSK21 is used both to read out the train identification data from the I²C-EEPROM on the backplane board and to control the I²C-I/O Module on the IFK21 adapter board, which provides the two outputs for controlling the signal lights in the drivers' cabins.

3.3.2.6 Storage medium of the DSK21

PCMCIA ATA-FLASH memory cards are used as a storage medium. The cards do not need a battery to retain the data. The system is equipped with one 16MB memory card. The storage medium can be easily removed, read out with a laptop and then put back again into the DSK21.

The storage medium is protected against unauthorised removal by a keylock.

<u>Storage types:</u>

PC-ATA card of 16MB capacity.

3.3.2.7 DSK21 Status LED

The DSK21 has a LED on the front panel. Various information, such as ready status and handling errors, are indicated to the user by means of this LED.

3.4 ZWG20

The ZWG20' function is to capture, process and pass distance covered and digital and analogue signals to the DSK21 (via ICOM – Interface) for recording the vehicle's speed, and to output speed and distance signals in different forms.
For further hardware description see

"Instruction Handbook ZWG20 Data Storage Cassette" (4AB729).

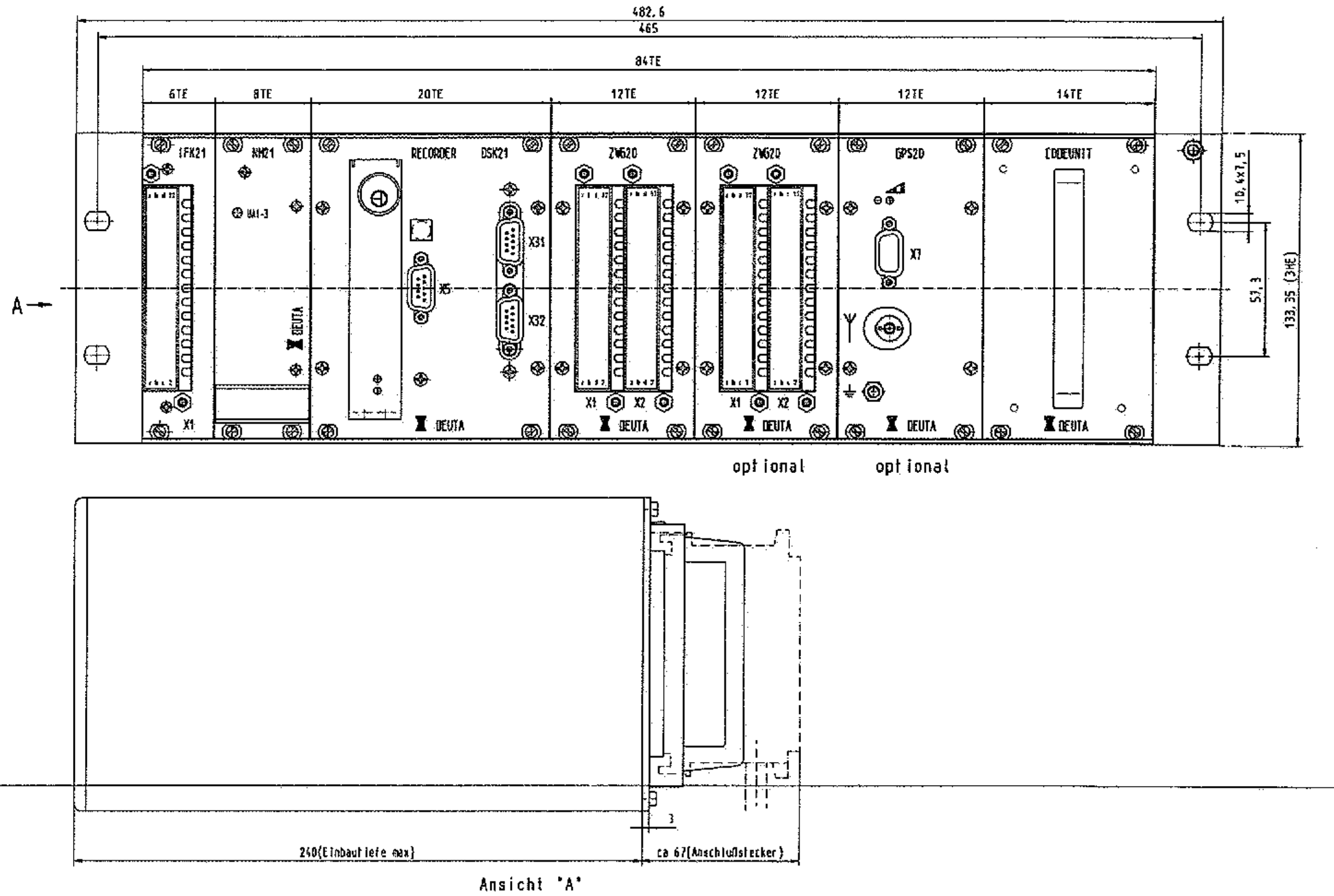
4 Description of the hardware implemented for IC4 (DSB)

4.1 Construction and mechanical system

4.1.1 Cartridge

An EMC-compliant 19“ sub rack (3hu, 84du) is used. In the basic version only the following modules are inserted: IFK21: M multiple pin strip on the front panel for the power supply, the ATC interface and fault output, the NM21 and DSK21 mains power supply and a ZWG20 module with a Type 1 extension card. The space on the 19“ rack that is not used (initially) is covered appropriately.

- IFK21, connection adapter with an M/F multiple pin strip on the front panel (power supply, ATC,...) — 3 hu, 4 du (basic)
- NM21 power pack — 3 hu, 8 du (basic)
- DSK21, adapter board including MVB — 3 hu, 20 du (basic)
  Note: The EFA21 is shipped with two special screws: In this way the DSK21 module can be sealed against unauthorised removing the DSK21 module.
- ZWG20 basic board, with expansion board, type 1 — 3 hu, 12 du (basic)
- Codeunit, that is used for reading the train ID — 3 hu, 14 du (basic)
  (Should also be fixed to the vehicle)



4.1.2 Wiring and earthing scheme

The subassemblies are to be arranged in a metal slide-in unit connected to the vehicle chassisInternal signals are dc-isolated from the external signals transferred in and out, including supply voltage, except for the service interface on the DSK21.

The frequency inputs, transmitter-supply outputs, frequency and distance-pulse outputs, analogue inputs and outputs may not be connected to the vehicle battery and must be fed in via screened lines. The lead screens are to be connected to the case potential of the EFA21a.
The supply-voltage feed and digital inputs and outputs may be connected to the vehicle battery with unscreened lines.

We recommend transferring all signals from the F strips (2 x ZWG20 + 1 x adapter board) to a terminal strip via multiconductor cables; distribution to the train system can be carried out from here. These cables and the terminal strip are not, however, part of the scope of delivery.

⇨For detailed information about wiring the EFA21a see document "9S9.160"
and "Instruction Handbook EFA21a" (4AB822GB) point 5.2.

4.1.3 Internal connection

The IFK21connection adapter, the DSK21 and the NM21 power pack module are wired together on a backplane board.
In addition, the backplane board contains an (I²C) EEPROM, which contains the train identification data and cable connectors, in order to connect the ZWG20 to the power supply (5V) via a ribbon cable and to connect the necessary ICOM signals.

Additional cable connectors for carrying out a simple, optional extension with a second ZWG20 and GPS20 are also provided on the backplane board.

<u>Tip:</u> The train identification data (locomotive number) in the I²C-EEPROM becomes invalid if the module frame is removed and must be reinputted if it is installed in another vehicle.

DSB has to draw up an instruction manual for changing the complete 19" rack. I.e. the new train ID has to be reinputted by using the corresponding codeplug.

4.2 Description of the inputs / outputs

4.2.1 IFK21 connection adapter with an M multiple pin strip on the front panel

The following signals are available on this connector strip:

- Supply voltage 24VDC (+ potential)
- Mass supply voltage
- 20mA TTY interface, passive, for ATC interface (TTY2 from additional DSK21 board)
  - TXD +
  - TXD –
  - RXD +
  - RXD –
  - Mass (shield)
- 2 Fault outputs (relay)
- SPI Interface from DSK21, e.g. for external, optional PMS Module

4.2.1.1 Gold cap buffered real time clock

There is a high-precision gold cap buffered real time clock on this board. Using a gold cap instead of a LI buffer battery offers the advantage of virtually maintenance free operation, however it only guarantees voltage bridging of 24 hours for the clock module.
The exactness of this clock is 4min / year. So the deviation after 2h is about 0,05sec, after 10h about 0,3sec and after 24 about 0,7 sec max..

The DSK21's internal system clock is synchronised with the precise RTC time at regular intervals. (For more details see 5.8 Time synchronisation)
This clock module is controlled by the I²C interface of the DSK21 wired via the backplane board.

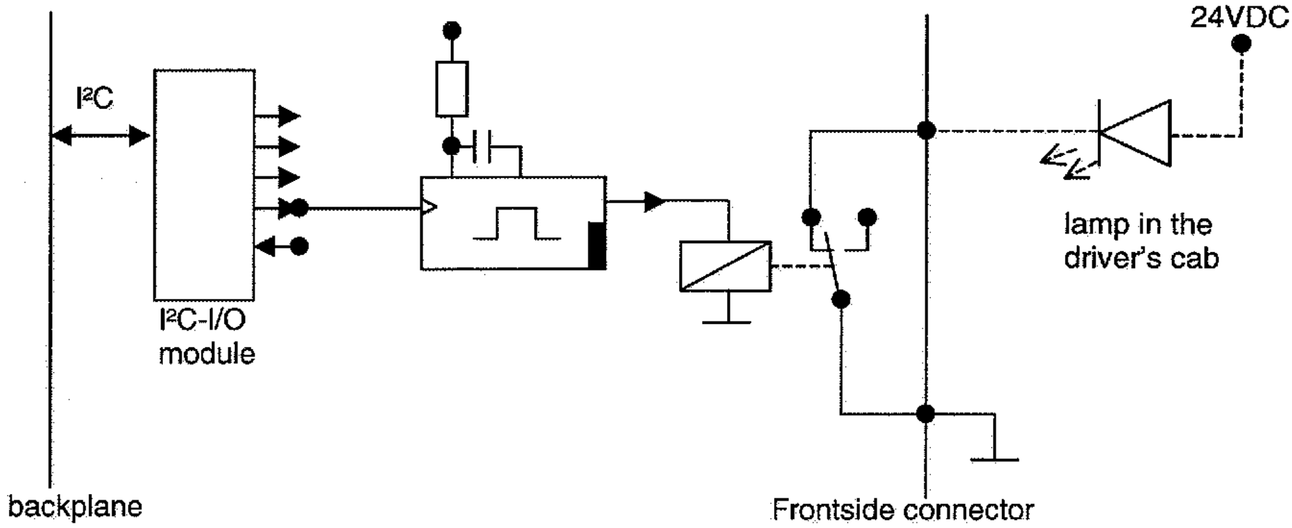
4.2.1.2 Outputs for fault lamps

The opener contact of a relay is used to control the fault signal lamps (LEDs) in the drivers' cabins.

The relay is controlled also by a digital output of the I²C–I/O module on this adapter board via a monoflop (see diagram). This monoflop will be triggered periodically by the DSK21 if the signal light is supposed to remain switched off. Otherwise, the relay returns to rest position and the fault signal lamps come on (⇨malfunction).

For further hardware description see

"Instruction Handbook IFK21 Interface Card " (4AB827GB).



The diagram shows the function of one LED. Control of the other LED is carried out in the same way.

4.2.2 DSK21

- All ZWG20 input signals are transmitted to the DSK21 via the internally wired ICOM interface.

- (The ZWG20 output signal Vout1 (Vact > 5km/h) is calculated and controlled by the ZWG20 itself. This also applies to the analogue outputs for the speed indicators in drivers cabin 1 and 2.)

- TTY interface, passive 20mA current loop interface for coupling to ATC. The connections are fitted to the F strip on the front panel of the adapter card IFK21 via the backplane board and the adapter card.

- I²C interface. An EEPROM with data for identifying the vehicle is located on the backplane board. This EEPROM can be read out and described via the I²C interface of the DSK21. Placement of this EEPROM on the backplane board guarantees the clear association of the EFA21a module with this installation rack. If the DSK21 module is replaced, this data is adopted during power-up from the DSK21.
  The vehicle identification data only has to be reinputted via the Codeplug if the installation frame is replaced.
  The I²C interface also controls the I/O module on the adapter board. This I/O module provides the digital output signals for the signal lights in the driver's cabin (see above).

4.2.3 ZWG20

Abbreviations:
BC = ZWG20 basic card
EXP1 = ZWG20 expansion card Type 1
V_{max} = Maximum vehicle speed
P_{max} = Maximum (braking air) pressure.
Dst = Driver status (driver's desk)

For further hardware description see

"Instruction Handbook ZWG20 " (4AB729).

4.2.4 Inputs

4.2.4.1 Digital inputs, dc-isolated

External, universal, digital channels, dc-isolated inputs

16 inputs (4 on the basic card + 12 on the expansion card)

For each input the connections are transferred to the connector individually, in such a way that they are immediately adjacent to one another. This means that in the mating connector the positive or negative poles are easily connected to a busbar.

4.2.4.2 Frequency inputs

There are two frequency inputs for recording distance, turning direction and actual speed. Each input has one signal adapter for DF transmitters.

In addition, the first frequency input has a second DF input for detecting turning direction. Two transmitters can thus be connected, one of them optionally with detection of turning direction (two-channel DF transmitter).

The DF inputs are designed for standard DEUTA DF transmitters (DF5, DF7, DF16, DF17, DF22). Only transmitters that run on 15 V may be used. The transmitter-supply and transmitter-input connections are transferred to the F connector separately to enable transmitters with an open-collector output (e.g. DF16) or open-emitter output to be used.

- type of used DF transmitter: DF16/1 S3.128 bad
- max. frequency: 10 kHz

4.2.4.3 Analogue inputs

The two analogue inputs are dc-isolated from the system, but have a common voltage source. The inputs are filtered through a first-order low-pass filter. The low-pass filter has a critical frequency of approx. 200 Hz (-3db).

- input current: 4 mA – 20 mA, load impedance 50 Ohm (⇨ 0…10bar)

4.2.5 Outputs

4.2.5.1 Relay output

Function	Output	Comment	Reference
v > 5km/h	Relay output 1.1	(switching threshold can be configured)	MSTD 8.005, page 16
Together with AB and DEUTA we agreed to activate a relay output, when DLU speed > 5km/h, althoug there is a difference to the specification MSTD8.005 page 16.			

4.2.5.2 Power supply outputs

There are two outputs for supplying the transmitters. They are dc-insulated from the system and from one another.

- voltage: 15V, proof against sustained short circuit

4.2.5.3 Analogue outputs

Two analogue outputs are provided. These are for supplying power to instruments/equipment and are dc-isolated from one another. It is not compulsory to insulate the outputs from each other, and only one output or none at all can be fitted, if necessary.

When the ZWG20 is switched on the outputs are 0 mA, until the software outputs a defined value. When the ZWG20 is switched off the outputs become 0mA. In the event of a watchdog reset the outputs become 0mA and remain 0mA until the software outputs a defined value.

The speed is outputted as an analogue value via these outputs.

- current output: 0 mA – 10 mA, load impedance <= 500 Ohm, (⇨ 0...250km/h)

4.3 Additional technical data of the EFA21a

- Power input of the total system: approx. 30W max.
- Weight: < 7 kg
- Installation mass see Point 4.1.1 Cartridge
- Protection category for EFA-System: IP20
- **Protection category of the PCMCIA ATA memory card:**
  1. operating temperature: -40 to +85°
  2. Shock approval 1000 G
  3. Vibration 15G

  IP-Protection IP54 is confirmed on the label of the card:
  IP54 means: complete protection:
  Dust protection: dust deposits are permissible but the amount must not impair the function of the device.
  Water protection: against splash water from all directions
- The system will be tested according to EN50155, NUP-T2 and BN411-002.

5 Softwaredescription

5.1 List of all recorded signals

5.1.1 DSK21 Input Signals, sorted by requirement references

No	Signalname	Origin	Implementation	Comments	Requirement references
1	Train identification	I²C-EEPROM on the backplane	LN = Intern_I2C_Loknummer	32Bit + OutputSignal_53 (Input from Codeplug)	MSTD8.005, page 5 Meeting in Pistoia KW37 / 02
2	Max Speed	Telegr. Type 2 Pack. Type H	VMZ = ATC_Vmax	250km/h	MSTD8.005, page 5
3	distance	ZWG20 (SSYS)	Weg = ZWG20_WegMeter	16Bit forward counter with 1m accuracy	MSTD8.005, page 6
4	speed	ZWG20 (VSYSY)	Vist = ZWG20_VIst	16Bit, 1km/h	MSTD8.005, page 6 and page 11 a)
5	Actual traction /brake effort	MVB ID:91.501 trac_act	Sp35 = MVB_dlu_i_trac_act		MSTD8.005, page 11 367EE00190B, Mod.2
6	wheel diameter	ZWG20 (Service-SW)	Sp70 = ZWG20_1_Wheel_Diameter_1	16Bit range: 800 … 860mm	MSTD8.005, page 6 Comments from DSB
7	time	MVB ID:91.100 timedate	Zeit = MVB_dlu_i_Teloc_Date_and_Time	32Bit, GMT	MSTD8.005, page 6
8	Forward from driver's desk 1	MVB ID: 91.514 trac_direc	Sp41 = MVB_dlu_i_trac_dir		MSTD8.005, page 11 (b 367EE00190B, Mod.2
9	Wheel slip	MVB ID: 91.519 wheel_slip	Sp43 = MVB_dlu_i_wheel_slip		MSTD8.005, page 12 (c 367EE00190B, Mod.2
10	Wheel slide	MVB ID: 91.517 wheel_slide	Sp42 = MVB_dlu_i_wheel_slide		MSTD8.005, page 12 (c 367EE00190B, Mod.2
11	Brake pipe pressure	ZWG20 AE1	Sp66 = ZWG20_1_Press_Main_Pipe	range: 0…10,0bar (4…20mA) accuracy 0,1bar	AA01MGU, Att.1, Signal: [8] MSTD8.005, page 12 (d
		ZWG20 AE2	Sp67 = ZWG20_1_PrsMainBrakePipe		AA01MGU, Att.1, Signal: [9] MSTD8.005, page 12 (d
12	Electro-magnetic rail brake active	ZWG20 DE1.3	Sp56 = ZWG20_1_ElDyn_Brake_ON		AA01MGU, Att.1, Signal: [14] MSTD8.005, page 12 (e
13a	Dynamic brake active	MVB ID: 41747/0	Sp106 = (Sp86) MVB_ccu_com0_UM_M1_HDAForce1	These signals are not logged directly. If the value of a signal is unequal "0", then the corresponding BOOLEAN signal (in brackets) becomes "1" and will be stored	MSTD8.005, page 12 (f ⇨Email 04.12.02 (Nesti)
13b		MVB ID: 41747/1	Sp107 = (Sp87) MVB_ccu_com1_UM_M4_HDAForce1		
13c		MVB ID: 41647/0	Sp108 = (Sp88) MVB_rio2_com0_UM_M1_HDAForce1		

No	Signalname	Origin	Implementation	Comments	Requirement references
13d		MVB ID: 41647/1	Sp109 = (Sp89) MVB_rio2_com1_UM_M4_HDAForce1		
14	Driver's desk 1 operated	MVB ID: 41.001 desk_enable	Sp34 = MVB_ccu_o_desk_enable		MSTD8.005, page 12 (g
15	DMA – Signals	ZWG DE0.1	Sp50 = ZWG20_1_DSD_01	DMA-signals shunting	MSTD8.005, page 12 Signals (h to k) AA01MGU, Att.1, Signals: [16.1] to [16.4] Comments from DSB
		ZWG DE0.2	Sp51 = ZWG20_1_DSD_02	DMA-signal testing	
		ZWG DE0.3	Sp52 = ZWG20_1_DSD_03	DMA-signal suspended	
		ZWG DE0.4	Sp53 = ZWG20_1_DSD_04	Activating of mobile DMA	
16	Traction cut off	ZWG DE1.4	Sp57 = ZWG20_1_Traction_cut_off		MSTD8.005, page 13 (l AA01MGU, Att.1, Signal: [15]
17	Traction-brake controller	MVB ID: 91.506 R1dmu_mode	Sp40 = MVB_dlu_i_R1dmu_mode		MSTD8.005, page 13 (m
18	Brake controller				MSTD8.005, page 13 (n
19	Filling of the brake pipe		NOT LOGGED ⇨ Email 28.11.02 (from Mr. Nesti)		MSTD8.005, page 13 (o ⇨Email 18.06.02 (Nesti)
20	Goods-passenger braking system selector G/P/R			NOT APPLICABLE	MSTD8.005, page 14 (p ⇨Email 18.06.02 (Nesti)
21	Driver's desk 2 operated	MVB		see MVB ID: 41.001 MSTD8.005, page 12 (g	MSTD8.005, page 14 (a ⇨Email 18.06.02 (Nesti)
22	Backward from driver's desk 1	MVB		see MVB ID: 91.514 MSTD8.005, page 11 (b	MSTD8.005, page 14 (b ⇨Email 18.06.02 (Nesti)
23	Goods-passenger braking system selector G/P/R			NOT APPLICABLE	MSTD8.005, page 14 (c ⇨Email 18.06.02 (Nesti)
24	Activation of typhoon	MVB ID: unknown TYP1_CMD	Sp45 = MVB_dlu_i_TYP1_CMD	MVB ID:91.525 ⇨ from Dlu_i	MSTD8.005, page 14 (d ⇨Email 18.06.02 (Nesti)
		MVB ID: unknown TYP2_CMD	Sp46 = MVB_dlu_i_TYP2_CMD	MVB ID:91.526 ⇨ from Dlu_i	
25	Operation of radio			NOT APPLICABLE	MSTD8.005, page 14 (e ⇨Email 18.06.02 (Nesti) Comments from DSB
26	Main-circuit breaker cut out request from the interference current monitor			NOT APPLICABLE	MSTD8.005, page 14 (f ⇨Email 18.06.02 (Nesti)
27	Main-circuit breaker switched			NOT	MSTD8.005, page 15 (g ⇨Email 18.06.02 (Nesti)

No	Signalname	Origin	Implementation	Comments	Requirement references
	off			APPLICABLE	Comments from DSB
28	Electrical heating switched off			NOT APPLICABLE	MSTD8.005, page 15 (h ⇨Email 18.06.02 (Nesti)

29	Air pressure in the brake cylinder	MVB-ID: 41.126 to 41.135,	Sp110 = MVB_ccu_o_pfa1 Sp111 = MVB_ccu_o_pfa2 Sp112 = MVB_ccu_o_pfa3 Sp113 = MVB_ccu_o_pfa4 Sp114 = MVB_ccu_o_pfa5 Sp115 = MVB_ccu_o_pfa6 Sp116 = MVB_ccu_o_pfa7 Sp117 = MVB_ccu_o_pfa8 Sp118 = MVB_ccu_o_pfa9 Sp119 = MVB_ccu_o_pfa10	These 10 signals are stored as B1 each	MSTD8.005, page 15 (i ⇨Email 04.12.02 (Nesti)
30	Direct brake			NOT LOGGED	MSTD8.005, page 15 (j ⇨Email 18.06.02 (Nesti)
31	Release of doors right/left			NOT LOGGED	MSTD8.005, page 15 (k ⇨Email 18.06.02 (Nesti)
32	Key/keyswitch for de-coupling activated	MVB ID:91.524 unc_key_stat	Sp44 = MVB_dlu_i_unc_key_stat		MSTD8.005, page 15 (l
33	Brake ON	ZWG DE1.1	Sp54 = ZWG20_1_Brake_ON		AA01MGU, Att.1, Signal: [10]
34	Emergency brake	ZWG DE1.2	Sp55 = ZWG20_1_Emergency_Brake		AA01MGU, Att.1, Signal: [13]
35	Electrodynamic brake ON	ZWG DE1.3	Sp56 = ZWG20_1_ElDyn_Brake_ON		AA01MGU, Att.1, Signal: [14]
36	Emergency brake valve ON (desk 1)	ZWG DE1.5	Sp58 = ZWG20_1_EmBrakeValve_Dst1		AA01MGU, Att.1, Signal: [11]
37	Emergency brake valve ON (desk 2)	ZWG DE1.6	Sp59 = ZWG20_1_EmBrakeValve_Dst2		AA01MGU, Att.1, Signal: [12]
38	ATC not in service	ZWG DE1.7	Sp60 = ZWG20_1_ATC_NotInService		AA01MGU, Att.2
38a	ATC main switch	ZWG DE1.8	Sp61 = ZWG20_1_ATC_main_switch		Comments from DSB ⇨meeting Oct. 09th, 2002
39	Emergency Brake (ZB)	ZWG DE1.9	Sp62 = ZWG20_1_Emerge_Brake_ZB		AA01MGU, Att.2
40	Service Brake (BB)	ZWG DE1.10	Sp63 = ZWG20_1_Service_Brake_BB		AA01MGU, Att.2

Further MVB – Signals

41	MVB_dlu_i_Teloc_Date_and_Time	MVB ID: 91.500	Zeit = MVB_dlu_i_Teloc_Date_and_Time	not logged directly used for synchronizing the RTC	
42	HI_VEH_DIST	MVB ID: 41.100	Sp33 = MVB_ccu_o_HI_VEH_DIST	(not required MVB-Signal ! ?)	(AA01MGU, Att.1, Signal: [7])
43	max_brake_M1_1	MVB ID:	Sp36 =	(not required	(AA01MGU, Att.1,

No	Signalname	Origin	Implementation	Comments	Requirement references
		91.502	MVB_dlu_i_max_brake_M1_1	MVB-Signal ! ?)	Signal: [7])
44	max_brake_M1_2	MVB ID: 91.503	Sp37 = MVB_dlu_i_max_brake_M1_2	(not required MVB-Signal ! ?)	(AA01MGU, Att.1, Signal: [7])
45	max_brake_M4_1	MVB ID: 91.504	Sp38 = MVB_dlu_i_max_brake_M4_1	(not required MVB-Signal ! ?)	(AA01MGU, Att.1, Signal: [7])
46	max_brake_M4_2	MVB ID: 91.505	Sp39 = MVB_dlu_i_max_brake_M4_2	(not required MVB-Signal ! ?)	(AA01MGU, Att.1, Signal: [7])
47	Batt_Fast	MVB ID: 91.507	Sp47 = MVB_dlu_i_Batt_Fast	(not required MVB-Signal ! ?)	(AA01MGU, Att.1, Signal: [7])

Further ATC - Signals

48	Brake Per Cent	Telegr. Type 2 Pack. Type %	BRH = ATC_Brake_Per_Cent		ATC – protocoll, Version 3 01.11.1998, 9.2
49	Train Length	Telegr. Type 2 Pack. Type L	ZL = ATC_Train_length		ATC – protocoll, Version 3 01.11.1998, 9.2
50	Wheel Diameter	Telegr. Type 2 Pack. Type J	Sp01 = ATC_Wheel_Diameter		ATC – protocoll, Version 3 01.11.1998, 9.2
51	ATC direction	Telegr. Type 2 Pack. Type R	Sp02 = ATC_Direction_Of_Travel		ATC – protocoll, Version 3 01.11.1998, 9.2
52	Actual Speed	Telegr. Type 3 Pack. Type K	Sp04 = ATC_V_actual	These signals are only logged directly in the process record. They are treated as analogue values ⇨ point 5.3	ATC – protocoll, Version 3 01.11.1998, 9.3
53	Surveillance Speed	Telegr. Type 3 Pack. Type G	Sp05 = ATC_V_survaillance		
54	Balise Information	Telegr. Type 4 Pack. Type a-h	Sp07 = ATC_Balise_Info_0 to Sp18 = ATC_Balise_Info_11		ATC – protocoll, Version 3 01.11.1998, 9.4
55	Balise Name	Telegr. Type 4 Pack. Type name	Sp19 = ATC_Balise_Name		ATC – protocoll, Version 3 01.11.1998, 9.4
56	Error Code	Telegr. Type G Pack. Type E	Sp21 = ATC_Errorcode		ATC – protocoll, Version 3 01.11.1998, 9.5
57	Operational Function	Telegr. Type a Pack. Type I	Sp25 = ATC_Operation_Func		ATC – protocoll, Version 3 01.11.1998, 9.7
58	Operational Information	Telegr. Type a Pack. Type n	Sp27 = ATC_Operation_Info		ATC – protocoll, Version 3 01.11.1998, 9.7
59	Lamp Test	Telegr. Type c Pack. Type m	Sp29 = ATC_Lamp_Test	This signal is also affected to the signal lamps immediately	ATC – protocoll, Version 3 01.11.1998, 9.8
60	SPAD	Telegr. Type 7 Pack. Type S	Sp31 = ATC_SPAD		ATC – protocoll, Version 3 01.11.1998, 9.11

Further internal signals

61	StartStop_Signal	calculated internally	Sp128 = Intern_StartStop_Signal	see point 5.5.3	MSTD8.005, point 5.6, page 11 (a

5.1.2 More details about ZWG20 signals

5.1.2.1 DSK21 input signals from ZWG20_1

- Weg = ZWG20_WegMeter ;actual DLU distance UNSIGNED16
- Vist = ZWG20_VIst ;actual DLU speed UNSIGNED16
- Sp49 = ZWG20_1_Fahrtrichtung ;⇨ direction of travel: BOOLEAN1
  The direction of travel is generated by the ZWG20 using the second channel of the DF16 (digital impulse sender) connected to frequency input „DF_Aux“ This signal is also stored

together with the internally calculated StartStop_Signal (Sp128) in the Start- and in the StopRecord.

- Sp50 = ZWG20_1_DSD_01 ;DE0.1 BOOLEAN1
- Sp51 = ZWG20_1_DSD_02, ;DE0.2 BOOLEAN1
- Sp52 = ZWG20_1_DSD_03 ;DE0.3 BOOLEAN1
- Sp53 = ZWG20_1_DSD_04 ;DE0.4 BOOLEAN1
- Sp54 = ZWG20_1_Brake_ON ;DE1.1 BOOLEAN1
- Sp55 = ZWG20_1_Emergency_Brake ;DE1.2 BOOLEAN1
- Sp56 = ZWG20_1_ElDyn_Brake_ON ;DE1.3 BOOLEAN1
- Sp57 = ZWG20_1_Traction_cut_off ;DE1.4 BOOLEAN1
- Sp58 = ZWG20_1_EmBrakeValve_Dst1 ;DE1.5 BOOLEAN1
- Sp59 = ZWG20_1_EmBrakeValve_Dst2 ;DE1.6 BOOLEAN1
- Sp60 = ZWG20_1_ATC_NotInService ;DE1.7 BOOLEAN1
- Sp61 = ZWG20_1_ATC_Main_Switch ;DE1.8 BOOLEAN1
- Sp62 = ZWG20_1_Emerge_Brake_ZB ;DE1.9 BOOLEAN1
- Sp63 = ZWG20_1_Service_Brake_BB ;DE1.10 BOOLEAN1
- Sp64 = (ZWG20_1_DE1_11) ;DE1.11 BOOLEAN1 (reserved, not logged)
- Sp65 = LokNbConnectorActiv ;DE1.12 BOOLEAN1 (for Codeplug only; not logged)
- Sp66 = ZWG20_1_Press_Main_Pipe ;AE1 UNSIGNED16
- Sp67 = ZWG20_1_PrsMainBrakePipe ;AE2 UNSIGNED16
- (Sp68) = (ZWG20_1_V1) ;internal speed V1 UNSIGNED16 (not logged)
- (Sp69) = (ZWG20_1_V2) ;internal speed V2 UNSIGNED16 (not logged)
- Sp70 = Intern_Wheeldiameter ;actual wheel diameter UNSIGNED16
  The actual wheel diameter is set by the service – PC via the Service interface of the DSK21.
- Sp72 = ZWG20_1_SW_Version ;SW-Version UNSIGNED32
- Sp73 = ZWG20_1_Config_Version ;Version of ZWG20-Configuration UNSIGNED32

5.1.2.2 DSK21 output signals to ZWG20_1

- There are no process signals sent from DSK21 to ZWG20_1.

5.1.3 More details about MVB signals

Used port numbers:	1145	source port of the DLU	freshness time: 1024ms
	1146	sink port of the DLU	sample time: 128ms
	200	sink port of the DLU	sample time: 128ms
	1110	sink port of the DLU	sample time: 140ms
	1120	sink port of the DLU	sample time: 140ms
	1130	sink port of the DLU	sample time: 140ms
	1140	sink port of the DLU	sample time: 140ms

The MVB device adress of the DLU is 10

5.1.3.1 DSK21 input signals from MVB

- Zeit = MVB_dlu_i_Teloc_Date_and_Time sinkport 1146 offset 0 TIMEDATE48
  Only the 32Bit seconds part of this signal is used. GMT is exspected.
  This signal is used for synchronizing the internal system clock and the gold cap buffered RTC on the IFK21 mdule. ⇨ see point 5.8 Time synchronisation
- Sp33 = MVB_ccu_o_HI_VEH_DIST sinkport 200 offset 0 UNSIGNED32
- Sp34 = MVB_ccu_o_desk_enable sinkport 200 offset 48 ANTIVALENT2
- Sp35 = MVB_dlu_i_trac_act sinkport 1146 offset 48 INTEGER16
  The signal Sp35 will not be logged directly. It is treated as an analogue signals, that will be logged either in crash memory or in operation memory, depending on the deviation relativ to the last logged value.
  ⇨ see point 5.3 Recording of analogue signals
- Sp36 = MVB_dlu_i_max_brake_M1_1 sinkport 1146 offset 64 INTEGER16
- Sp37 = MVB_dlu_i_max_brake_M1_2 sinkport 1146 offset 80 INTEGER16
- Sp38 = MVB_dlu_i_max_brake_M4_1 sinkport 1146 offset 96 INTEGER16
- Sp39 = MVB_dlu_i_max_brake_M4_2 sinkport 1146 offset 112 INTEGER16
- Sp40 = MVB_dlu_i_R1dmu_mode sinkport 1146 offset 128 INTEGER8
- Sp41 = MVB_dlu_i_trac_dir sinkport 1146 offset 136 ANTIVALENT2
- Sp42 = MVB_dlu_i_wheel_slide sinkport 1146 offset 138 BOOLEAN1
- Sp43 = MVB_dlu_i_wheel_slip sinkport 1146 offset 139 BOOLEAN1
- Sp44 = MVB_dlu_i_unc_key_stat sinkport 1146 offset 144 ANTIVALENT2
- Sp45 = MVB_dlu_i_TYP1_CMD sinkport 1146 offset 146 BOOLEAN1
- Sp46 = MVB_dlu_i_TYP2_CMD sinkport 1146 offset 147 BOOLEAN1
- Sp47 = MVB_dlu_i_Batt_Fast sinkport 1146 offset 148 BOOLEAN1
- Sp110 = MVB_ccu_o_pfa1 sinkport 200 offset 166 BOOLEAN1
- Sp111 = MVB_ccu_o_pfa2 sinkport 200 offset 167 BOOLEAN1
- Sp112 = MVB_ccu_o_pfa3 sinkport 200 offset 168 BOOLEAN1
- Sp113 = MVB_ccu_o_pfa4 sinkport 200 offset 169 BOOLEAN1
- Sp114 = MVB_ccu_o_pfa5 sinkport 200 offset 170 BOOLEAN1
- Sp115 = MVB_ccu_o_pfa6 sinkport 200 offset 171 BOOLEAN1
- Sp116 = MVB_ccu_o_pfa7 sinkport 200 offset 172 BOOLEAN1
- Sp117 = MVB_ccu_o_pfa8 sinkport 200 offset 173 BOOLEAN1
- Sp118 = MVB_ccu_o_pfa9 sinkport 200 offset 174 BOOLEAN1
- Sp119 =MVB_ccu_o_pfa10 sinkport 200 offset 175 BOOLEAN1
- Sp106 = MVB_ccu_com0_UM_M1_HDAForce1 sinkport 1110 offset 16 UNSIGNED16
- Sp107 = MVB_ccu_com1_UM_M4_HDAForce1 sinkport 1130 offset 16 UNSIGNED16
- Sp108 = MVB_rio2_com0_UM_M1_HDAForce1 sinkport 1120 offset 16 UNSIGNED16
- Sp109 = MVB_rio2_com1_UM_M4_HDAForce1 sinkport 1140 offset 16 UNSIGNED16

- CycleS1 = MVB_dlu_i_life sinkport 1146 offset 240 UNSIGNED8
- CycleS2 = MVB_ccu_o_life sinkport 200 offset 240 UNSIGNED8
- CycleS3 = MVB_ccu_com0_life sinkport 1110 offset 112 UNSIGNED8
- CycleS4 = MVB_ccu_com1_life sinkport 1130 offset 112 UNSIGNED8
- CycleS5 = MVB_rio2_com0_life sinkport 1120 offset 112 UNSIGNED8
- CycleS6 = MVB_rio2_com1_life sinkport 1140 offset 112 UNSIGNED8

The Life signals CycleS1 to CycleS6 will not be logged, but utilized.

5.1.3.2 DSK21 output signals to MVB

- OutputSignal_54 = DLU_Train_Ident sourceport 1145 offset 0 UNSIGNED32
  This signal is the Train Set Number. It is read once after power on, copied in the source port and then never changed. (except after changing this train identification number via codeplug connected to the ZWG20 module.)
- OutputSignal_50 = DSK21_Errors sourceport 1145 offset 32 BITSET32
- OutputSignal_55 = DLU_Press_Main_Pipe sourceport 1145 offset 64 UNSIGNED16
- OutputSignal_56 = DLU_PrsMainBrakePipe sourceport 1145 offset 80 UNSIGNED16
- OutputSignal_33 = EFA21_Status sourceport 1145 offset 96 BITSET8
- OutputSignal_51 = ZWG20_1_errors sourceport 1145 offset 104 BITSET8
- OutputSignal_52 = ZWG20_2_errors sourceport 1145 offset 112 BITSET8
- QuellCounter1_1 = QuellCounter1_1 sourceport 1145 offset 240 UNSIGNED8 (lifesignal)
- OutputSignal_53 = Check_variable_MVB_Port sourceport 1145 offset 254 ANTIVALENT2
  This check variable always has the value = 01 (Okay)

5.1.4 More details about ATC signals

5.1.4.1 DSK21 input signals from ATC

- BRH = ATC_Brake_Per_Cent Telegr. Type 2 Pack. Type % UNSIGNED8
- ZL = ATC_Train_length Telegr. Type 2 Pack. Type L UNSIGNED16
- VMZ = ATC_Vmax Telegr. Type 2 Pack. Type H UNSIGNED16
- Sp01 = ATC_Wheel_Diameter Telegr. Type 2 Pack. Type J UNSIGNED16
- Sp02 = ATC_Direction_Of_Travel Telegr. Type 2 Pack. Type R ANTIVALENT2
- Sp04 = ATC_V_actual Telegr. Type 3 Pack. Type K UNSIGNED16
- Sp05 = ATC_V_survaillance Telegr. Type 3 Pack. Type G UNSIGNED16
  The signals Sp04 and Sp05 will not be logged directly (only in the ProcessRecord). They are treated as analogue signals, that will be logged in crash memory and in operation memory, dependent of the deviation relativ to the corresponding last logged value.
  ⇨ see point 5.3 Recording of analogue signals
- Sp07 = ATC_Balise_Info_0 Telegr. Type 4 Pack. Type a-h UNSIGNED8
  ...
  Sp18 = ATC_Balise_Info_11 Telegr. Type 4 Pack. Type a-h UNSIGNED8
- ~~Sp19 = ATC_Balise_Name UNSIGNED8~~
  Each time a telegram type 4 is received the 12 bytes are logged in Sp07 to Sp18 and the corresponding value of the actual packet type (‚a' to ‚h') is logged in Sp19. This complete data record is logged in the crash and in the operation memory.

- Sp21 = ATC_Errorcode Telegr. Type G Pack. Type E UNSIGNED16

- Sp23 = ATC_HKT_Speed_Info Telegr. Type H Pack. Type n UNSIGNED16
  This signal will never be logged. The telegram type H will be treated as an „unknown telegram“, because it is not expected in „pure Danish“ ATC.
- Sp25 = ATC_Operation_Func Telegr. Type a Pack. Type l ENUM8
- Sp27 = ATC_Operation_Info Telegr. Type a Pack. Type n ENUM8
- Sp29 = ATC_Lamp_Test Telegr. Type c Pack. Type m UNSIGNED8
  If the value 'T' is received, the signal lights in driver's cabin 1 and in driver's cabin 2 are switched **on**.
  If these were **on** at the time, the state does not change.
  If these were **off** at the time, the signal lights are switched **off** again after a delay of approx. 5 seconds, unless the command to switch them **off** has been received before.

  If the value 'S' is received, the signal lights in driver's cabin 1 and driver's cabin 2 are switched **off**.
  If these were **off** at the time, the state does not change.
  If these were **on** at the time, the signal lights are switched **on** again after a delay of approx. 5 seconds, unless the command to switch them **on** has been received before.

  All other characters in the package are rejected.
- Sp31 = ATC_SPAD,256 Telegr. Type 7 Pack. Type S UNSIGNED32

All ATC signals will be logged immediately after receipt (like binary signals) except "ATC_V_actual" and „ATC_V_survaillance" see above.

If an ATC – telegram is received with unvalid data the rejected telegram "N" is sent to ATC with the data "A" (application error, -> data validation). Simultaneously a diagnostic message "ATC_Undefined_value" is logged and the configured default value (=0) is assigned to the corresponding ATC-variable(s). In this case the corresponding bit in the signal "SinkportState" is set and with this change the data record with the signal "SinkportState" (GP_REC32) will be logged to indicate that this ATC – port is not valid.

5.1.4.2 DSK21 output signals to ATC

There is only one signal sent to ATC from the DSK21. This is the actual speed of the DLU (signal Vist = ZWG20_VIst) that is sent in the packet type „K“ in the telegram type 6 (positive receipt).

Note: The Telegram Type ‚N‘ is sent as a Rejected Telgram with the Error Codes:
‚1‘ : Checksum error
‚2‘ : Timing error
‚A‘ : Application error (data validation error)
‚ ‘ (blank): rejected in general
⇨ see ATC protocoll – specification !

5.2 Recording of binary signals

In general, all binary signals are recorded into the crash and the operation memory every time the value changes. BITSET and ENUM variables are also treated as binary signals.
All signals received from ATC (except the speed information received with telegram type 3) are logged immediately, whether they have changed or not.
Additionally the data of ATC telegram type 7 (SPAD) are recorded into the SPAD storage. The size of this storage is configured with 128kB (lowest possible size) so it is ensured that at least the last 10 passings without applying the key „passage stop“ are recorded.

5.3 Recording of analogue signals

Analogue signals are only recorded if the actual value differs from the last logged value by a fixed value. The first value is logged straight away the first time a signal is received by the DSK21 after power on or after a communication error.

List of all recorded analogue values

Signal name	Deviation when logged in crash memory	Deviation when logged in operation memory
ZWG20_1_Press_Main_Pipe	0,2 bar (⇨ 2% of 10,0bar)	1,0 bar (⇨ 10% of 10,0bar)
ZWG20_1_PrsMainBrakePipe	0,2 bar (⇨ 2% of 10,0bar)	1,0 bar (⇨ 10% of 10,0bar)
ATC_V_actual	1 km/h (⇨ 0,4% of 250 km/h)	5km/h (⇨ 2% of 250km/h)
ATC_V_survaillance	1 km/h (⇨ 0,4% of 250 km/h)	5km/h (⇨ 2% of 250km/h)
MVB_dlu_i_trac_act	4% (⇨ 2% of 200%)	10% (5% of 200%)

The analogue signals of the Brake force applied by HD1 and HD2 retarder are not logged directly. But there is a binary signal related to every of these analogue signals.
Their value is = „0“, if the corresponding analogue value is = „0“ and becomes = „1“ if the corresponding analogue value becomes > „0“. Only these binary signals will be stored whenever they have changed.

Analogue signal	corresponding, internal binary signal, that will be logged
Sp106 = MVB_ccu_com0_UM_M1_HDAForce1	Sp86 = Intern_MVB_ccu_UM_M1_HDAForce1
Sp107 = MVB_ccu_com1_UM_M4_HDAForce1	Sp87 = Intern_MVB_ccu_UM_M4_HDAForce1
Sp108 = MVB_rio2_com0_UM_M1_HDAForce1	Sp88 = Intern_MVB_rio_UM_M1_HDAForce1
Sp109 = MVB_rio2_com1_UM_M4_HDAForce1	Sp89 = Intern_MVB_rio_UM_M4_HDAForce1

5.4 Recording the ProcessRecord

The process record contains all signals that are to be recorded by the DSK21. Analogue values are only stored with their actual, last received value in this record type. If a signal is "not valid" (not received yet), its default value is registered in the process record. The validity (default value) of every signal is indicated in the signal "SinkportState", that is also stored in the ProcessRecord.
The process record is stored at least every 60 seconds in the crash memory and at least every 600 seconds in the operation memory.

5.5 Recording the travelling data

The Vactual record is stored with the speed information (Vist = ZWG20_VIst) together with the distance (Weg = ZWG20_WegMeter) and the actual time (GMT)

5.5.1 Recording in crash memory

in the crash memory:
actual speed = 0 to 10km/h every 2m
actual speed = 11 to 20km/h every 5m
actual speed = 21 to 60km/h every 10m
actual speed = more than 60km/h every 20m

⇨ There is no further data compression in the crash memory!

5.5.2 Recording in operation memory

actual speed = 0 to 50km/h	every 10m
actual speed = 51 to 90km/h	every 50m
actual speed = 91 to 110km/h	every 100m
actual speed = more than 110km/h	every 300m

5.5.2.1 Data compression:

The Vactual record will only be stored in operation memory in these intervals if the value of the speed differs by more than 3km/h relative to the last recorded value. (But at least every 65536m.)

5.5.3 StartStop – Signal

A StartStop-Signal (Antivalent2) is generated by monitoring the travelled way over a time period of 2sec:
The StartStop-Signal becomes 01 (movement) when the travelled way is more than ½ circumference of the wheel during 2sec.
The StartStop-Signal becomes 10 (standstill) when the travelled way is less than ¼ circumference of the wheel during 2sec.
The StartStop-Signal becomes 00 (invalid) when there is no way signal received from the ZWG20.
If there is an error the StartStop-Signal becomes 11 (This state is not used in the actual implementation)

Everytime the StartStop-Signal changes its value it it is recorded together with the Start – or StopRecord. (The Start – and StopRecords are used to synchronize the evaluation software.)

5.6 Adjustable parameters

The following parameters can be adjusted easily in the configuration of the DSK21 (or ZWG20):

1. The speed limits and distance interval for recording the Vactual record in the crash memory.
2. The speed limits and distance interval for recording the Vactual record in the operation memory.
3. The data compression of the Vactual record ON/OFF for the crash memory (actually: OFF)
4. The data compression of the Vactual record ON/OFF for the operation memory (actually: ON)
5. The deviation of the speed to store the Vactual record in the crash memory, if data compression is (ON).
6. The deviation of the speed to store the Vactual record in the operation memory, if data compression is (ON). (actual value: 3km/h)
7. The default value of every single process value.
8. The absolute difference between the ATC actual speed and the ZWG20 speed when a fault message has to be sent and recorded. (actual value: 10km/h)
9. The duration of the difference between the ATC actual speed and the ZWG20 speed before a fault message has to be sent and recorded. (actual value: 50s)
10. The absolute difference between the last recorded value of an analogue signal and the actual value if the analogue signal is to be stored in the crash memory. This difference can be adjusted for every analogue value individually.
11. The absolute difference between the last recorded value of an analogue signal and the actual value if the analogue signal is to be stored in the operation memory. This difference can be adjusted for every analogue value individually.
12. The minimum time period for storing the process record in the crash memory. (actual value: 60 seconds)
13. The minimum time period for storing the process record in the operation memory. (actual value: 600seconds)
14. All Error- and Warning messages individually to affect the signal lamps (or not)
15. The debounce time of the digital inputs (ZWG20). (actual value = 50ms)
16. The scale of the two analogue outputs (speed indicators). (actual value: 0...10mA: 0...250km/h)
17. The scale and the resolution of the two analogue inputs (brake pressure). (actual value 4...20mA: 0...10,0bar with a resolution of 0,1bar).
18. ...

5.7 *Diagnostic system*

5.7.1 DSK21 errors

The BITSET32 signal „DSK21_Errors“ is sent via MVB: Port 1145, Bit – Offset: 0.

Bit No	Meaning	The point of view of maintnance	The point of view of the the driver	Remarks
Bit 0	Configuration error detected	Try to reload the configuration to the DSK21	The system isn't able to start, no logging possible	possible result of the selftest
Bit 1	Battery of the RTC empty	Change battery on the IFK21	There is no valid time available until the time signal is sent via MVB: No logging while internal time not valid !	possible result of the selftest (not used with goldcap)
Bit 2	Battery of the RTC bad	Change battery on the IFK21	The system is working correctly, but the battery has to be changed	(not used with goldcap)
Bit 3	ZWG20_1 not obtainable	Look for reason with Service – Software Change ZWG20 module	There is no logging of ZWG signals possible. Perhaps there is no indication of speed from the DLU	The communication between DSK21 and ZWG20 failed
Bit 4	(ZWG20_2_not_obtainable)			(reserved for option)
Bit 5	(GPS20_not_obtainable)			(reserved for option)
Bit 6	(ATC_not_obtainable)	Look for reason with Service – Software Check ATC connection	No ATC signals can be logged	reserved (not required)
Bit 7	Wrong train ID	Preformat PC card, check Loknumber in the I²C eeprom ⇨ Service SW	No data will be logged	
Bit 8	Missing_Data_from_MVB	Look for reason with Service – Software Check MVB connection	No or not all MVB signals can be logged	
Bit 9 to Bit 14	(reserved)			always = „0“
Bit15	Internal clocktime invalid	Check RTC on the IFK21 module (possibly battery empty)	There is no valid time available until the time signal is sent via MVB:	
Bit 16	(Current fault signal lamp1)	–	–	(I_{LED1} < 3,5mA) ⇨ not used !
Bit 17	(Current fault signal lamp2)	–	–	(I_{LED2} < 3,5mA) ⇨ not used !
Bit 18	ATC DLU speed deviation more than 10km	Check ATC connection, Check speed indicator of the DLU's odometer		The ATC and DLU speed differ >=10km/h for 50 seconds
Bit 19 to Bit 31	(reserved)			always = „0“

5.7.2 EFA21 status

The BITSET8 signal „EFA21 status" is sent via MVB: Port 1145, Bit – Offset: 32.

Bit No	Meaning	The point of view of maintnance	The point of view of the the driver	Remarks
Bit 0	general failure in the EFA21	Look at „DSK21 errors"	No data will be logged	
Bit 1	(reserved)			always = „0"
Bit 2	Communication error	Look at „DSK21 errors" Check ATC connection Check MVB connection Check ZWG20 status (⇨ service software)	No or not all data can be logged	
Bit 3	(reserved)			always = „0"
Bit 4	(reserved)			always = „0"
Bit 5	Missing data	Look at „DSK21 errors" Check ATC connection Check MVB connection Check ZWG20 status (⇨ service software)	No or not all data can be logged	
Bit 6	PC card not ready	insert PC card preformat PC card investigate the DSK21 status (⇨ service software)	There is no valid PC card in the slot of the DSK21	
Bit 7	(reserved)			always = „0"

5.7.3 ZWG20 errors

The BITSET8 signal „ZWG20_1 errors" is sent via MVB: Port 1145, Bit – Offset: 40.

Bit No	Meaning	The point of view of maintnance	The point of view of the the driver	Remarks
Bit 0	Fault Impulse sender 1	failure of channel 1 of the DF16/1	the speed will be indicated correctly (by channel 2)	the direction of travel cannot be calculated, if one channel fails.
Bit 1	Fault Impulse sender 2	failure of channel 2 of the DF16/1	the speed will be indicated correctly (by channel 1)	
Bit 2	Underflow pressure main pipe	check connections		
Bit 3	Underflow pressure main brake pipe	check connections		
Bit 4	(reserved)			always = „0"
Bit 5	(reserved)			always = „0"
Bit 6	(reserved)			always = „0"
Bit 7	(reserved)			always = „0"

5.7.4 Signal lamps

- The signal lamps in the driver cabs are „ON“ when the EFA21a is out of service.
- After power on they are „ON“ until the PC card has been initialised and all communication has started correctly.
- The following messages will activate the signal lamps .The signal lamps will be switched „ON“ if at least one of the following messages is avtive. They will be switched „OFF“ if none of the following messages is active:
  - „Configuration error detected“ ⇨ Bit 0 of the signal „DSK21_Errors“
  - „ZWG20_1 not obtainable“ ⇨ Bit 3 of the signal „DSK21_Errors“
  - „Wrong train ID“ ⇨ Bit 7 of the signal „DSK21_Errors“
  - „Missing_Data_from_MVB“ ⇨ Bit 8 of the signal „DSK21_Errors“
  - „Internal clocktime invalid“ ⇨ Bit 15 of the signal „DSK21_Errors“
  - „ATC DLU speed deviation more than 10km“ ⇨ Bit 18 of the signal „DSK21_Errors“
  - „General failure in the EFA21“ ⇨ Bit 0 of the signal „EFA21 status“
  - „Communication error“ ⇨ Bit 2 of the signal „EFA21 status“
  - „Missing data“ ⇨ Bit 5 of the signal „EFA21 status“
  - „PC card not ready“ ⇨ Bit 6 of the signal „EFA21 status“
  - „Fault Impulse sender 1“ ⇨ Bit 0 of the signal „ZWG20_1 errors“
  - „Fault Impulse sender 2“ ⇨ Bit 1 of the signal „ZWG20_1 errors“
  - „Underflow pressure main pipe“ ⇨ Bit 2 of the signal „ZWG20_1 errors“
  - „Underflow pressure main brake pipe“ ⇨ Bit 3 of the signal „ZWG20_1 errors“

A distinction between errors and warning is actually not made.
All other messages easiliy can be configured also to affect the signal lamps!

5.8 Time synchronisation

There is a precise real time clock on the IFK21 module. This RTC is buffered by a gold cap.
The gold cap will not be tested, but an unvalid time is detected after power on, if the goldcap had been discharged. Every time an unvalid time is detected a fault message will be sent via MVB and the signal lamps will go ON.

Additionally the RTC – time becomes unvalid:

1. After downloading a new operation software to the DSK21,
2. If the RTC – time at PowerOn is more than 24h later as the last stored time in the internal FLASH.
   Note: Every time the EFA21a receives a powerfail signal (PowerOff), the actual time value (if valid) will be stored in the internal FLASH memory of the DSK21.

In case of using a goldcap:

1. The RTC has no valid time at PowerOn:
   The RTC will be ignored. The corresponding message will be sent and the internal clocktime will be unvalid until the signal „MVB_dlu_i_Teloc_Date_and_Time" is received from the MVB or a new time value is received from the service PC.

2. The RTC has a valid time at PowerOn:
   The actual time of the RTC will be copied into the internal system clock if the RTC time has a valid value.
   A valid value means: later than 01.01.2002, 00:00:00 and later than the last stored time in the internal FLASH memory of the DSK21, but less or equal than 24h later than the last stored time. ⇨ Then the first stored data record has a valid time stamp already!.

- If the signal „MVB_dlu_i_Teloc_Date_and_Time" is received from the MVB the RTC and the internal system clock will be updated with the value of this MVB time signal if there is a deviation of more than 1 sec between the MVB – time and the internal system time. The sample time of the MVB – Port (1146), that contains this time signal is 128ms, so every change of a second is recognized. In that way under normal conditions the exactness of all time stamps of the recorded data is <= +/– 1sec.

- The internal system clock will be set backwards only if a time value from the service PC is received, that is earlier than the internal system clock or if three consecutive values from the MVB are received, that are earlier than the internal system clock. (Normally never more than 1sec)

- If the internal system clock has to be corrected backwards, a corresponding diagnostic message will be logged into the internal diagnostic memory and into the maintenance memory on the PC card. Additionally the process record will be logged into the crash and operation memory on the PC card to enable the evaluation software to synchronize correctly.

- If there is no communication with the MVB the internal system clock will be synchronized with the actual, precise RTC time in a period of 30min (this time period is adjustable in the configuration of the DSK21).

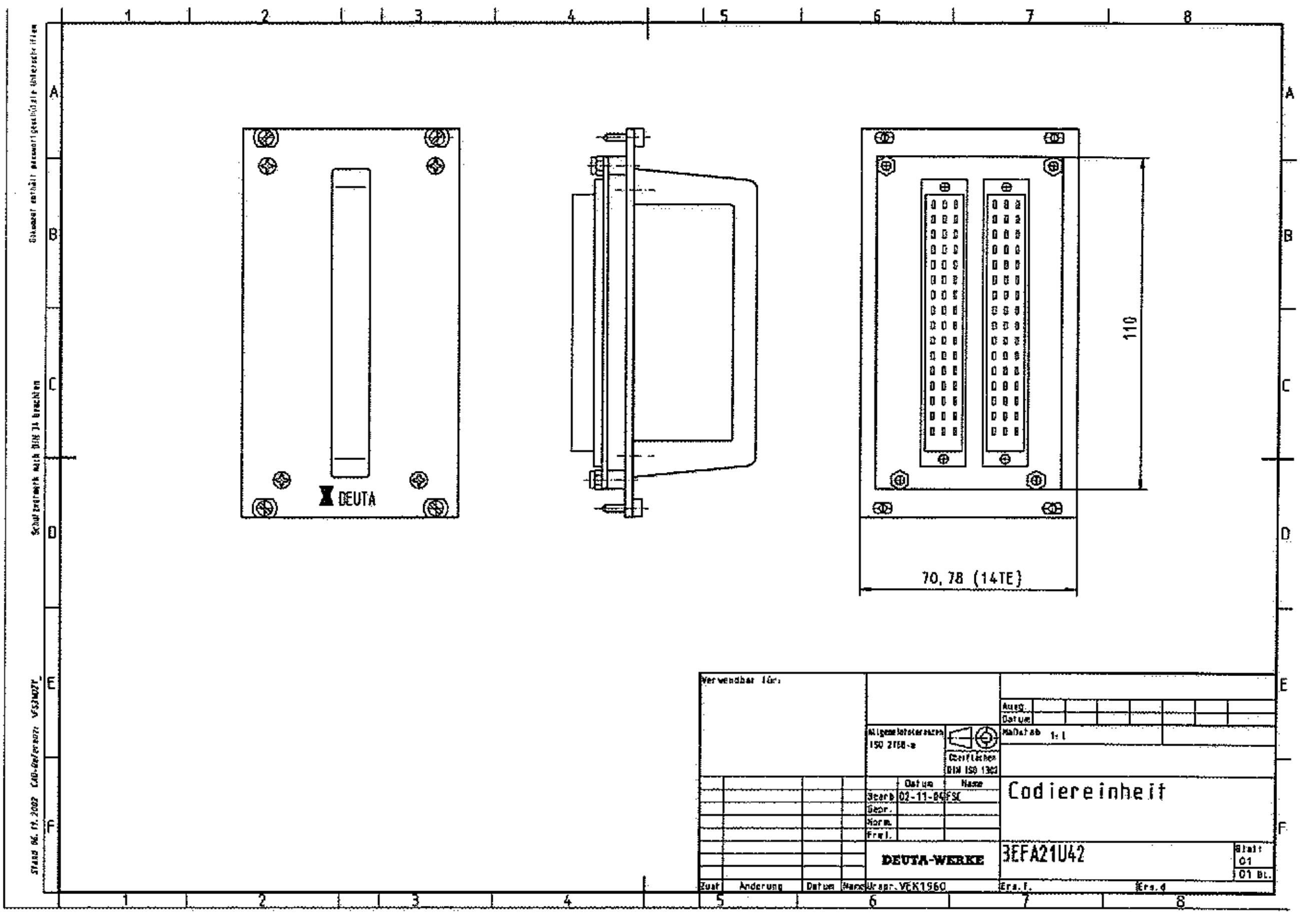
- On power fail the actual time is copied into the internal FLASH memory of the DSK21 in order to enable the time plausibility check at next power on.

- If a new time value is received vom the service PC, the RTC and the internal system clock will be updated with this time value.

5.9 Train identification number

The train identification number is an unsigned32 value that is stored in the I²C EEPROM on the backplane board.
The value can only be set in the range 1...9 999 by a special code plug, that is to be connected to the ZWG20 i.e. during the initial operation (see below).
During the initializing procedure of a new PC card the train ID is read out of the EEPROM and stored in the header of the PC card. Additionally the train ID will be stored in the process record and sent via MVB.
If a PC card is inserted in the PCMCIA slot and the train ID on the card differs from the value in the EEPROM, the card will be rejected and no data will be stored.
If you have to change the 19" rack, the train ID has to be updated in the new rack by the special code plug. The exchange of any other module doesn't affect the train ID number.

5.9.1 Design of the codeplug



Drawing of the Codeplug

There are 16 solder bridges on the PCB that each is connected to a DI of the ZWG20:
open (default) Bit = „0"
closed:Bit = „1"
Only Bit15 (DI1.12) is closed by default (codeplug detect signal). The Bit14 must not become „1"!

The plug can be put aside at the very right position of the 19" rack instead of the blind cover (14TE).

5.9.2 Handling of the codeplug

- connect the codeplug to the ZWG20 module
- switch ON the EFA21

  The status LED will flash slowly if the codeplug is detected.

  If there is an error: The value that is read from the plug is „0" or more than 9999,
There is an error in writing the value into the EEPROM.

  then the status LED will flash in a faster rythm.
- switch OFF the EFA21 and remove the codeplug and connect the standard plugs to the ZWG20.

To program the codeplug you only have to convert the decimal train ID number to binary code (max 14 Bits). All Bits = „1" you have to close the corresponding solder bridge of the PCB of the codeplug.

6 Steps to bring into use the EFA21a

- Check all HW – connections.
- Turn power on
- Set the train identification number (⇨ using the code plug coded with the train ID)
- Set the actual wheel diameter: There is applied a 2 channel impulse sender, so the wheel diameter 2 always has to be set to the same value like the wheel diameter 1 ! (⇨ service PC)
- Insert a preformatted PC – card into the PCMCIA slot and close the cover.
- Control the DSK21 status (EFA21 satus) on the service PC
- If the card is OK and there is no communication error the EFA21a is ready for use.
- For further diagnostic functions see the description of the service software.

5. Indhold af Kurveregisteret.

5.0 Indledning.

Kurveregisteret beskriver kurver i alle hovedspor. Hver linie i registeret beskriver en kurve med evt tilhørende overgangskurve(r) og/eller rampe(r).

5.1. Registeropbygning.

Registeret er opbygget med linier, der hver beskriver en kurve. For hver delstrækning/spor findes en overskrift svarende til registernøglen, sådan som den er beskrevet i afsnit 4. I linien, der beskriver de enkelte kurver, er den første km-angivelse dog en del af registernøglen.

Hver registerlinie indeholder følgende oplysninger om den valgte kurve:

- O-pæl1 : Første tangentpunkt i første overgangskurve (= kilometerangivelsen i registernøglen)
- OKL1 : Længden af første overgangskurve i meter (Et tilføjet S angiver s-formet overgangskurve)
- KURVET1: Placeringen af første kurvetavle - (= ende af første overgangskurve og begyndelsen af hovedkurven)
- KVL : Længden af hovedkurven i meter
- RADIUS : Hovedkurvens radius i meter. Ved tilføjelsen H hhv V angives om kurven går til højre eller venstre (set i kilometerretningen)
- OVH : Overhøjden i hovedkurven i millimeter

- KURVET2: Placeringen af anden kurvetavle (= ende af hovedkurven og begyndelsen af anden overgangskurve)

- OKL2. : Længden af anden overgangskurve i meter (Et tilføjet S angiver s-formet overgangskurve)

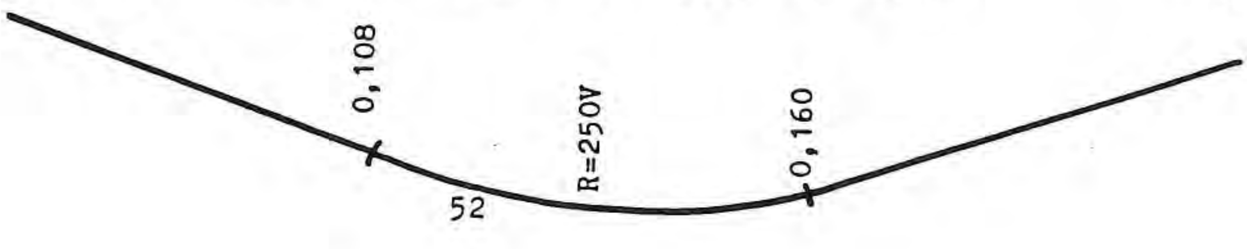
- O-PÆL2 : Sidste tangentpunkt i anden overgangskurve

De enkelte kurver (linier i registeret) vises uden indskudt blank linie, hvis kurverne er sammenhængende evt overlappende. Blank linie indskydes, hvis kurverne ikke er i forbindelse med hinanden, dvs der er et ret sporstykke mellem kurvens O-pæl2 og næste kurves O-pæl1. Se iøvrigt afsnit 5.5.

5.2. Kurver uden overgangskurve.

Såfremt første overgangskurve mangler, er km-angivelsen for O-PÆL1 og KURVET1 den samme, og OKL1 er lig med O. Tilsvarende vil der ved mangel af anden overgangskurve være ens km-angivelse for KURVET2 og O-PÆL2, og OKL2 vil være O.

STRKNR.	SPOR	AFSNIT								
O-PÆL1	OKL1	KURVET1	KVL	RADIUS	OVH	KURVET2	OKL2	O-PÆL2	BEM	DATO
011	000	004	Kh							
0.108	0	0.108	52	250V	0	0.160	0	0.160		1075



Annex D: Coefficients in final model.

Note: Seemingly insignificant variables are kept in the model as they interact with others. Thus the p-value in the 5th column does not adequately represent a test probability for excluding these variables from the model.

Coefficients:

	Estimate	Std. Error	z value	Pr(>|z|)	
(Intercept)	-2.464e+01	1.866e+00	-13.207	< 2e-16	***
T_2	-5.465e+00	7.573e-01	-7.217	5.30e-13	***
TD_2	1.462e+00	5.016e-01	2.915	0.003557	**
VS_10	3.115e+00	3.727e-01	8.359	< 2e-16	***
TKE	1.354e+00	1.775e-01	7.625	2.44e-14	***
Bremsekraft	-1.495e+00	1.816e-01	-8.232	< 2e-16	***
hastighed	-5.015e-03	5.366e-03	-0.935	0.349971	
skov2.index	4.181e+00	9.928e-01	4.212	2.54e-05	***
daemning2.index	-1.078e-01	8.544e-02	-1.262	0.206942	
afgravning2.index	9.032e-02	1.983e-02	4.554	5.26e-06	***
I(Bremsekraft^2)	-4.687e-02	1.577e-02	-2.971	0.002967	**
I((T_2)^2)	2.741e-01	3.069e-02	8.931	< 2e-16	***
TD_2.6h	3.174e+00	9.711e-01	3.268	0.001082	**
TD_2.7h	-6.617e+00	8.057e-01	-8.213	< 2e-16	***
TD_2.8h	1.847e+00	2.715e-01	6.803	1.02e-11	***
TD_2.4h	-4.856e+00	6.680e-01	-7.269	3.63e-13	***
T_2.6h	4.804e+00	6.664e-01	7.209	5.63e-13	***
T_2.3h	-4.255e+00	9.643e-01	-4.413	1.02e-05	***
krumning	-2.085e+00	5.655e-01	-3.686	0.000228	***
PRES.5h	-3.950e-01	5.348e-01	-0.739	0.460206	
VS_10.6h	-1.270e+00	3.144e-01	-4.040	5.35e-05	***
GLOR.3h	-4.761e-01	1.192e-01	-3.993	6.53e-05	***
block.temporal	2.721e+00	3.588e-01	7.584	3.36e-14	***
skov2.2km.index	-1.429e+01	5.471e+00	-2.611	0.009018	**

```
IC4                            3.051e+00  9.123e-01   3.345 0.000824 ***
Day                            3.208e+00  4.568e-01   7.024 2.16e-12 ***
I(Day^2/10)                   -3.179e+00  5.626e-01  -5.650 1.60e-08 ***
I(Day^3/1000)                  1.273e+01  2.651e+00   4.804 1.56e-06 ***
buske2.index                   1.699e+00  5.595e-01   3.036 0.002396 **
skov2.1km.index                2.061e+01  3.354e+00   6.143 8.09e-10 ***
GLOR                           1.244e-02  2.784e-03   4.467 7.93e-06 ***
I(Day^4/10000)                -1.749e+00  4.091e-01  -4.276 1.91e-05 ***
buske2.1km.index               2.802e+01  9.177e+00   3.054 0.002259 **
buske2.2km.index              -5.656e+01  1.725e+01  -3.278 0.001045 **
PRES.24h                      -3.045e-01  1.008e-01  -3.021 0.002518 **
T_2.5h                        -1.402e+01  1.705e+00  -8.221  < 2e-16 ***
TD_2.5h                        6.398e+00  1.239e+00   5.162 2.44e-07 ***
VS_10.5h                       4.223e+00  6.938e-01   6.086 1.16e-09 ***
GLOR.5h                        4.723e-01  1.183e-01   3.991 6.58e-05 ***
T_2.4h                         1.384e+01  1.780e+00   7.772 7.70e-15 ***
VS_10.4h                      -4.160e+00  7.501e-01  -5.546 2.92e-08 ***
PRES.3h                        2.987e+00  5.941e-01   5.028 4.96e-07 ***
VS_10.3h                       1.540e+00  4.604e-01   3.346 0.000821 ***
TD_2:hastighed                 2.327e-02  3.169e-03   7.341 2.12e-13 ***
hastighed:IC4                  2.503e-02  6.629e-03   3.775 0.000160 ***
IC4:I(hastighed^2/100)        -2.254e-02  3.459e-03  -6.516 7.23e-11 ***
skov2.index:block.temporal    -3.352e+00  5.827e-01  -5.752 8.83e-09 ***
Bremsekraft:daemning2.index   -3.315e-02  1.119e-02  -2.962 0.003055 **
Bremsekraft:IC4                4.939e-01  1.038e-01   4.757 1.96e-06 ***
hastighed:daemning2.index     -3.054e-03  6.241e-04  -4.894 9.90e-07 ***
TD_2:krumning                  6.226e-01  1.421e-01   4.382 1.17e-05 ***
block.temporal:IC4             2.373e+00  3.653e-01   6.497 8.21e-11 ***
T_2:IC4                        1.804e+00  2.859e-01   6.311 2.77e-10 ***
TD_2:IC4                      -1.448e+00  2.329e-01  -6.215 5.13e-10 ***
VS_10:IC4                     -9.363e-01  1.437e-01  -6.514 7.34e-11 ***
```

```
block.temporal:Day              3.501e-02  8.606e-03   4.068 4.74e-05 ***
VS_10:Day                      -9.441e-02  1.011e-02  -9.342  < 2e-16 ***
hastighed:skov2.index          -3.089e-02  1.072e-02  -2.881 0.003966 **
T_2:buske2.1km.index            2.190e+01  5.761e+00   3.802 0.000144 ***
TD_2:buske2.1km.index          -3.868e+01  6.481e+00  -5.969 2.39e-09 ***
buske2.1km.index:T_2.8h        -4.679e+00  1.506e+00  -3.106 0.001894 **
hastighed:TD_2.7h               8.700e-03  1.399e-03   6.220 4.99e-10 ***
TD_2.7h:buske2.1km.index        7.102e+00  1.930e+00   3.681 0.000233 ***
TD_2.6h:skov2.2km.index         1.792e+00  2.283e-01   7.850 4.16e-15 ***
krumning:VS_10.6h               8.263e-02  1.410e-02   5.862 4.58e-09 ***
VS_10.6h:skov2.2km.index       -1.243e+01  2.190e+00  -5.677 1.37e-08 ***
PRES.5h:T_2.5h                  1.360e-01  1.892e-02   7.187 6.60e-13 ***
PRES.5h:VS_10.5h               -9.049e-02  1.619e-02  -5.588 2.30e-08 ***
PRES.5h:TKE.5h                 -1.015e-01  1.675e-02  -6.058 1.38e-09 ***
T_2.5h:VS_10.5h                -1.514e-02  1.650e-03  -9.173  < 2e-16 ***
PRES.5h:IC4                     8.456e-01  1.515e-01   5.583 2.37e-08 ***
krumning:T_2.5h                -1.351e-01  2.481e-02  -5.444 5.20e-08 ***
hastighed:TD_2.5h              -1.603e-02  2.362e-03  -6.786 1.16e-11 ***
skov2.1km.index:TD_2.5h        -9.453e-01  1.715e-01  -5.511 3.56e-08 ***
daemning2.index:VS_10.5h        8.391e-03  1.945e-03   4.314 1.60e-05 ***
skov2.2km.index:VS_10.5h        1.483e+01  2.606e+00   5.692 1.26e-08 ***
skov2.1km.index:GLOR.5h        -5.143e-02  7.549e-03  -6.813 9.55e-12 ***
skov2.2km.index:GLOR.5h         4.654e-02  9.067e-03   5.133 2.85e-07 ***
Bremsekraft:TD_2.4h             3.115e-02  4.992e-03   6.240 4.37e-10 ***
GLOR.3h:VS_10.3h               -2.711e-04  7.545e-05  -3.593 0.000327 ***
T_2.3h:Day                      1.793e-02  3.080e-03   5.821 5.85e-09 ***
T_2.3h:skov2.2km.index         -1.699e+00  3.591e-01  -4.732 2.22e-06 ***
skov2.2km.index:I(Day^3/1000) -4.952e-01  1.533e-01  -3.231 0.001234 **
hastighed:buske2.2km.index      3.501e-01  1.180e-01   2.966 0.003018 **
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

ANNEX E:

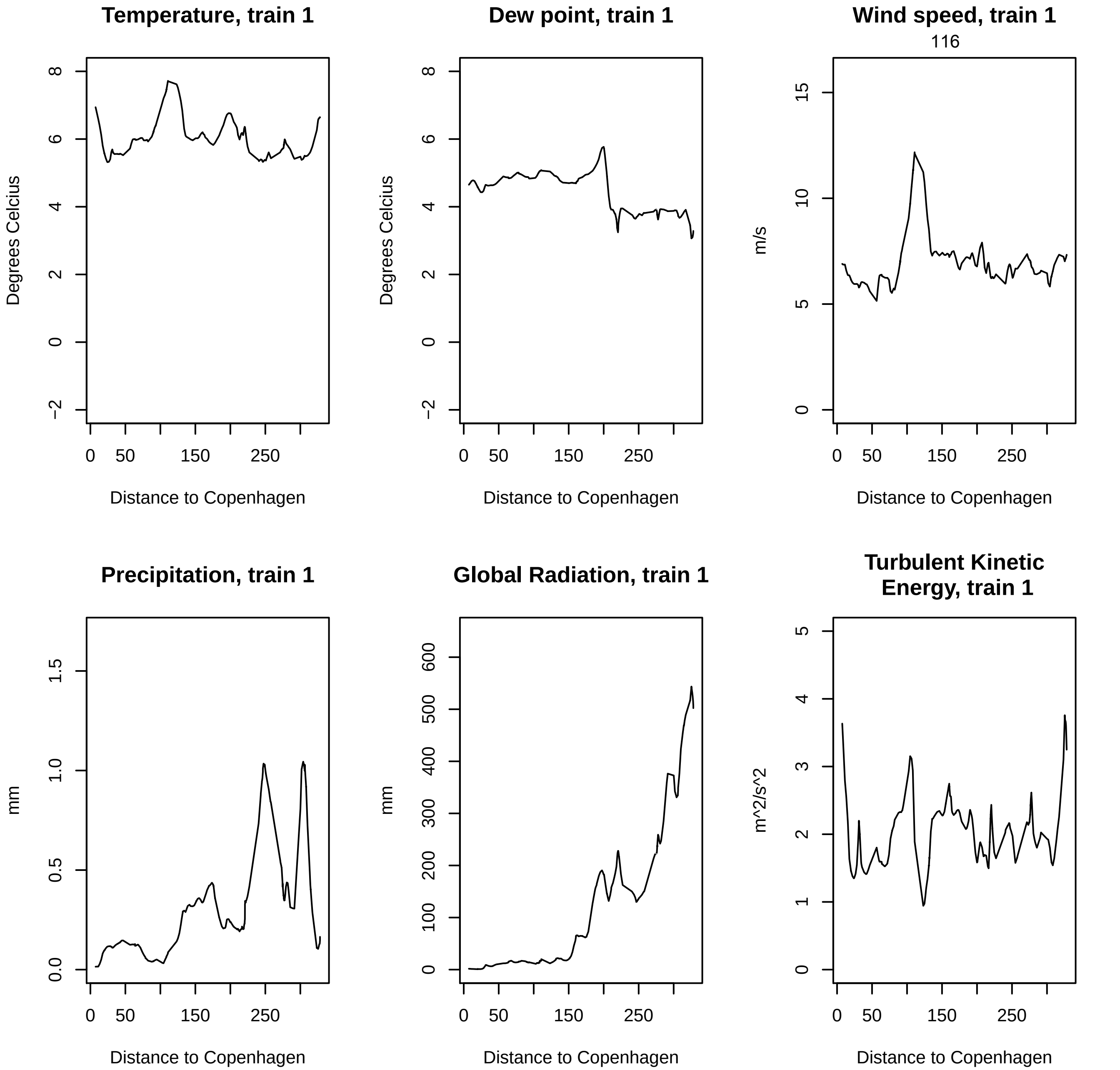
Distances to Copenhagen Central Station for reference stations.

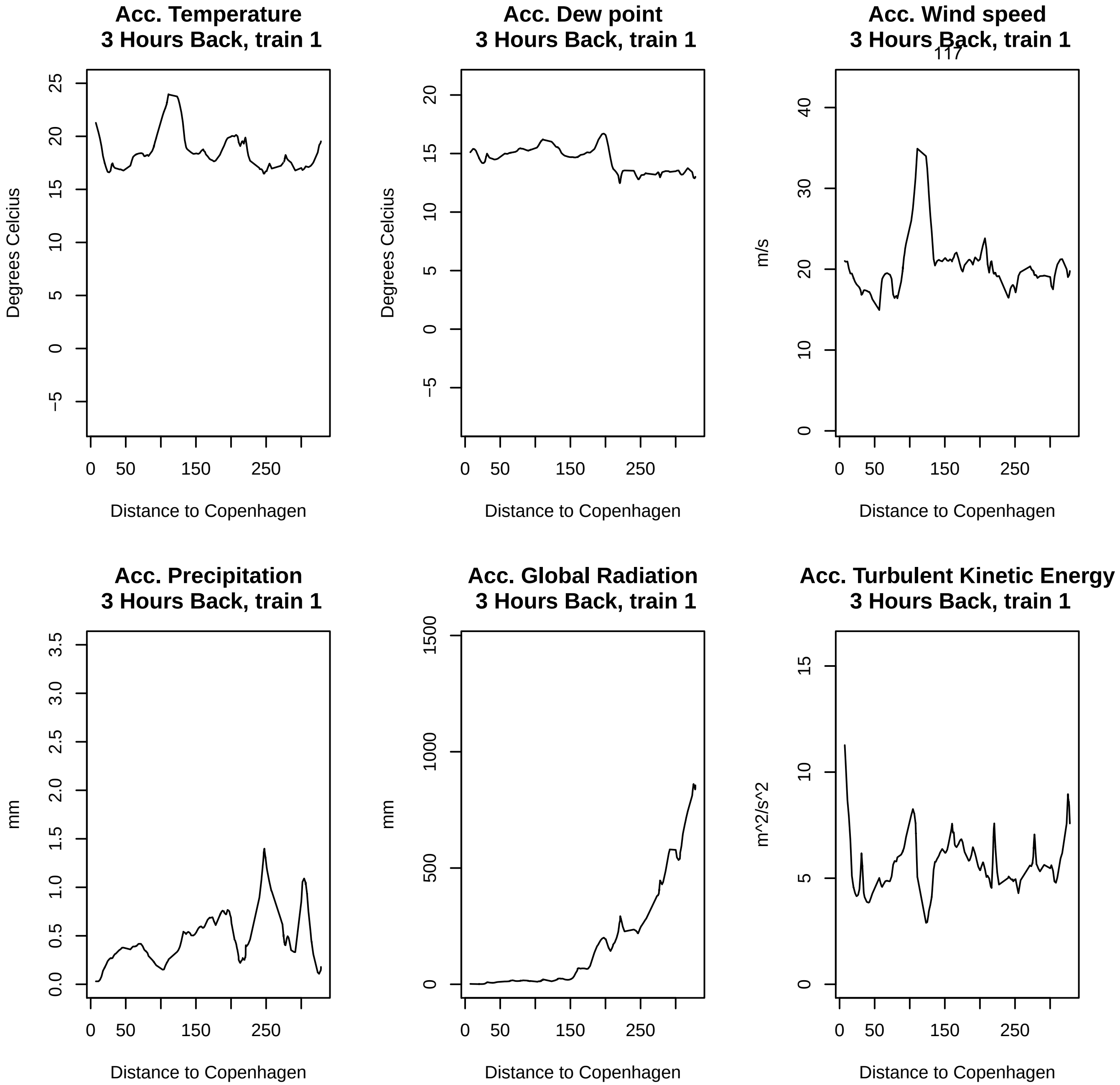
Station	Distance to Copenhagen Central Station/km
Glostrup	11.214
Høje Tåstrup	19.5
Hedehusene	24.176
Trekroner	28.3
Roskilde	31.253
Viby Sjælland	42.475
Borup	49.725
Kværkeby	49.725
Ringsted	63.904
Fjenneslev	71.5
Sorø	78.342
Slagelse	92.91
Forlev	100
Korsør	108.268
Sprogø	120.2
Nyborg	131.6
Hjulby	136.648
Ullerslev	141.544
Marslev	151.023
Odense	160.32
Holmstrup	168.996
Tommerup	175.485
Skalbjerg	178.753
Bred	181.121
Aarup	184.855
Gelsted	190.209
Ejby	194.802
Nørre Åby	200.113
Kauslunde	204.288
Middelfart	210.382
Snoghøj	216.212
Fredericia	220.585
Brejning	235.423
Vejle	246.305
Hedensted	261.346
Horsens	277.685
Hovedgård	292.16
Skanderborg	306.35
Hørning	314.819
Viby Jylland	324.329
Århus	328.119

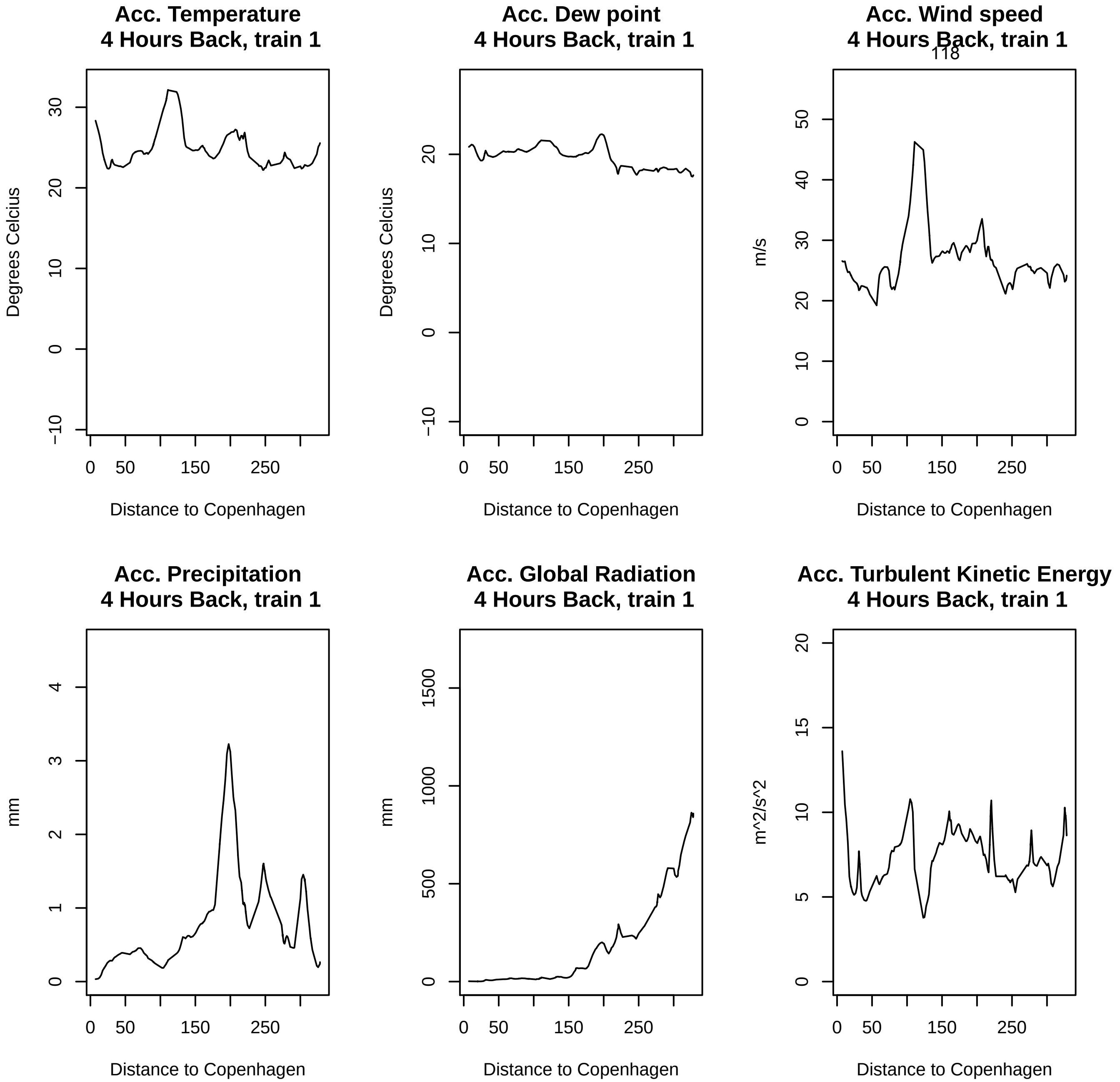
Annex F: Relations between train numbers used in Annexes G-I, and litra, calendar day and train type.

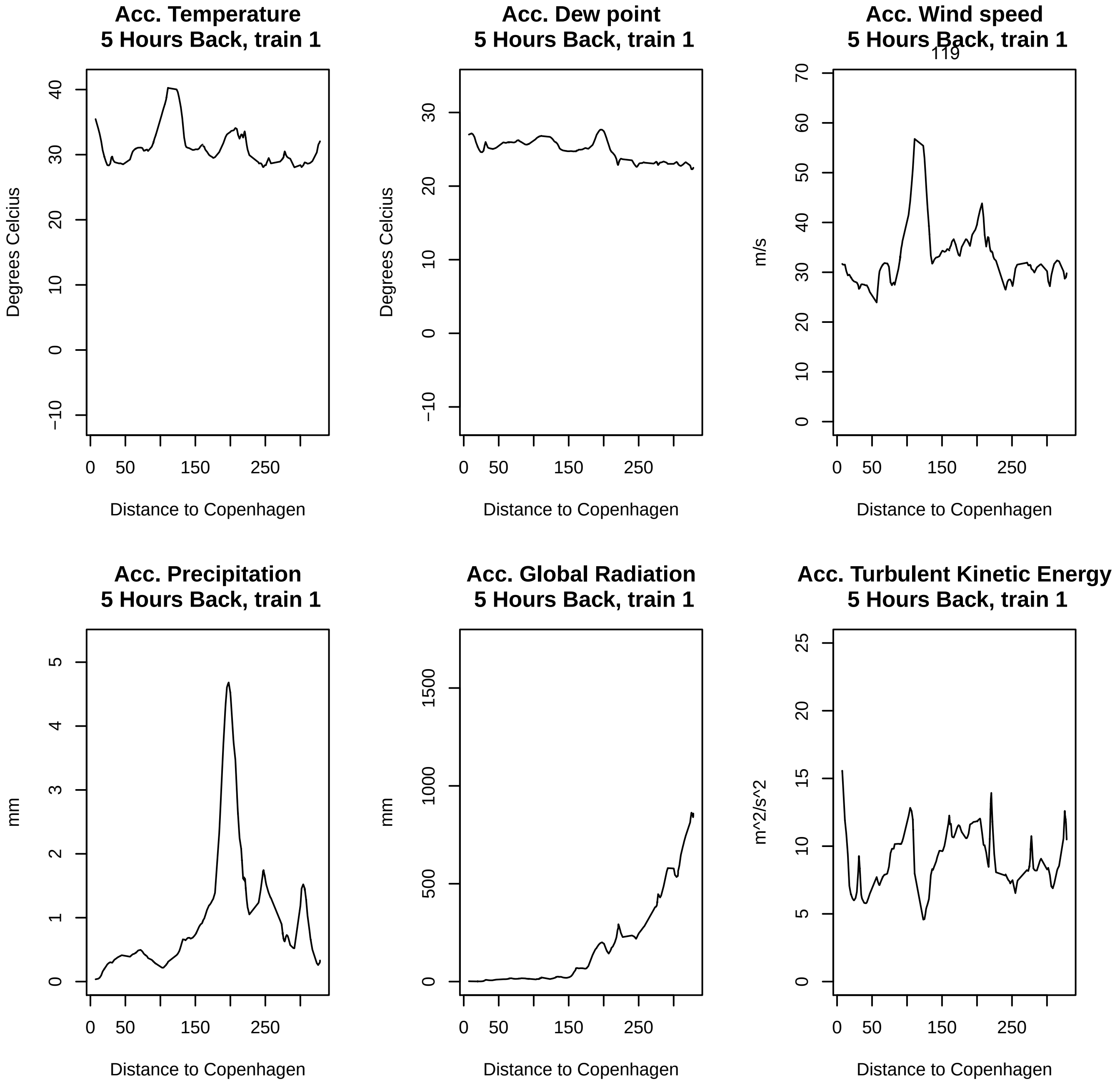
Train no.	Day	Registered Train Number	Litra	Type
1	2012-11-02	121	5006	IC3
2	2012-11-02	23	5036	IC3
3	2012-11-02	8107	5657	IC4
4	2012-11-07	121	5063	IC3
5	2012-11-06	23	5083	IC3
6	2012-11-06	8107	5646	IC4
7	2012-11-07	23	5025	IC3
8	2012-11-07	8107	5653	IC4
9	2012-11-13	121	5032	IC3
10	2012-11-13	23	5077	IC3
11	2012-11-13	8107	5653	IC4
12	2012-11-19	121	2030	IC3
13	2012-11-19	23	5093	IC3
14	2012-11-19	8197	5639	IC4
15	2012-11-20	121	2038	IC3
16	2012-11-20	8107	5642	IC4
17	2012-11-23	121	2026	IC3
18	2012-11-23	8107	5650	IC4
19	2012-11-28	121	2027	IC3
20	2012-11-28	23	5078	IC3
21	2012-11-28	8107	5642	IC4
22	2012-10-29	121	5005	IC3
23	2012-10-29	23	5053	IC3
24	2012-10-29	8107	5645	IC4
25	2012-11-29	121	2044	IC3
26	2012-11-29	23	5045	IC3
27	2012-11-29	8107	5648	IC4
28	2012-10-31	121	5012	IC3
29	2012-10-31	23	5045	IC3
30	2012-10-31	8107	5657	IC4

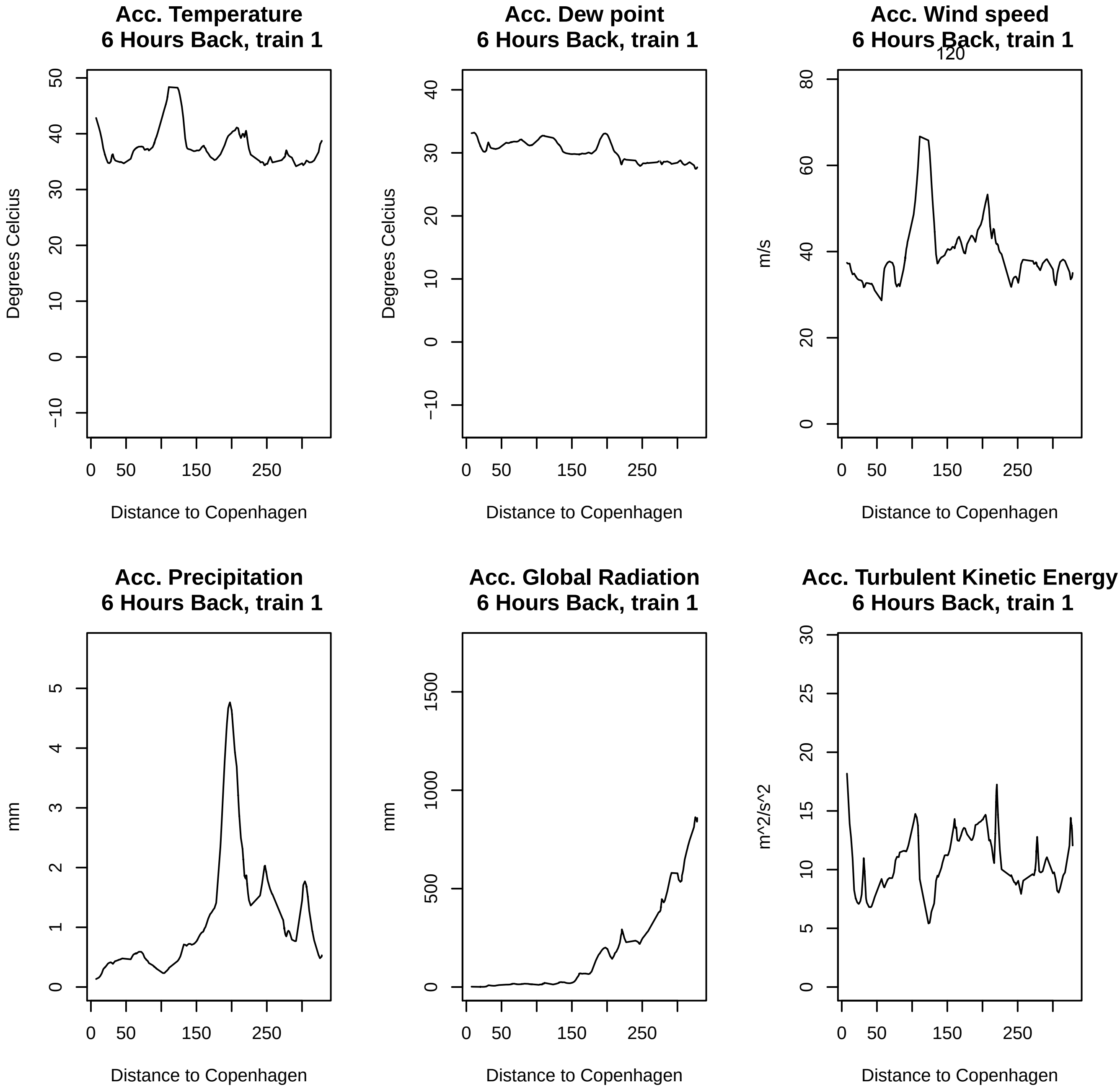
Annex G: Environmental data along the train routes, immediate and accumulated backwards in time.

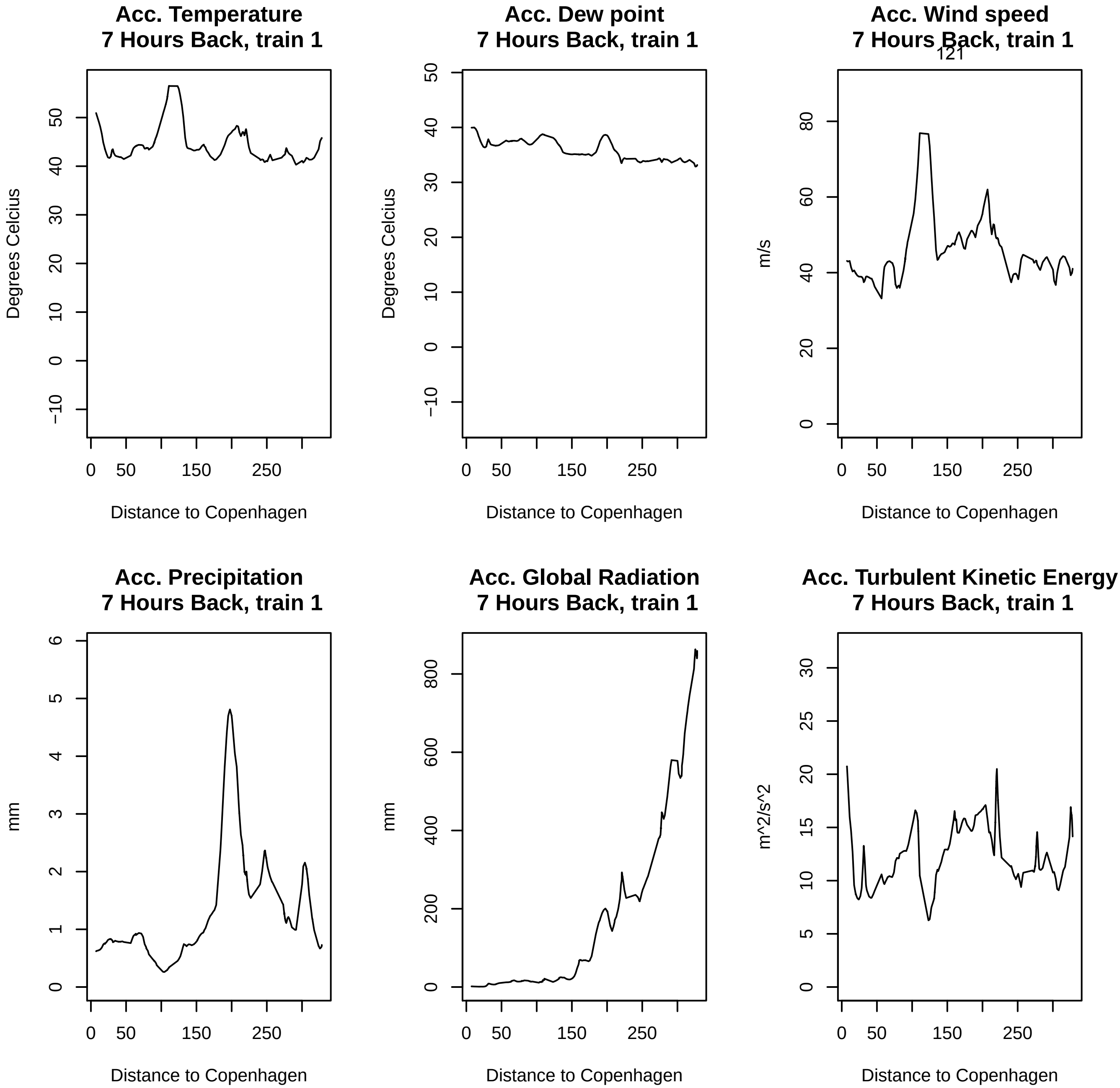

Temperature, train 1
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 1
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Wind speed, train 1
m/s
0
5
10
15
0
50
150
250
Distance to Copenhagen
Precipitation, train 1
mm
0.0
0.5
1.0
1.5
0
50
150
250
Distance to Copenhagen
Global Radiation, train 1
mm
0
100
200
300
400
500
600
0
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 1
m^2/s^2
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen

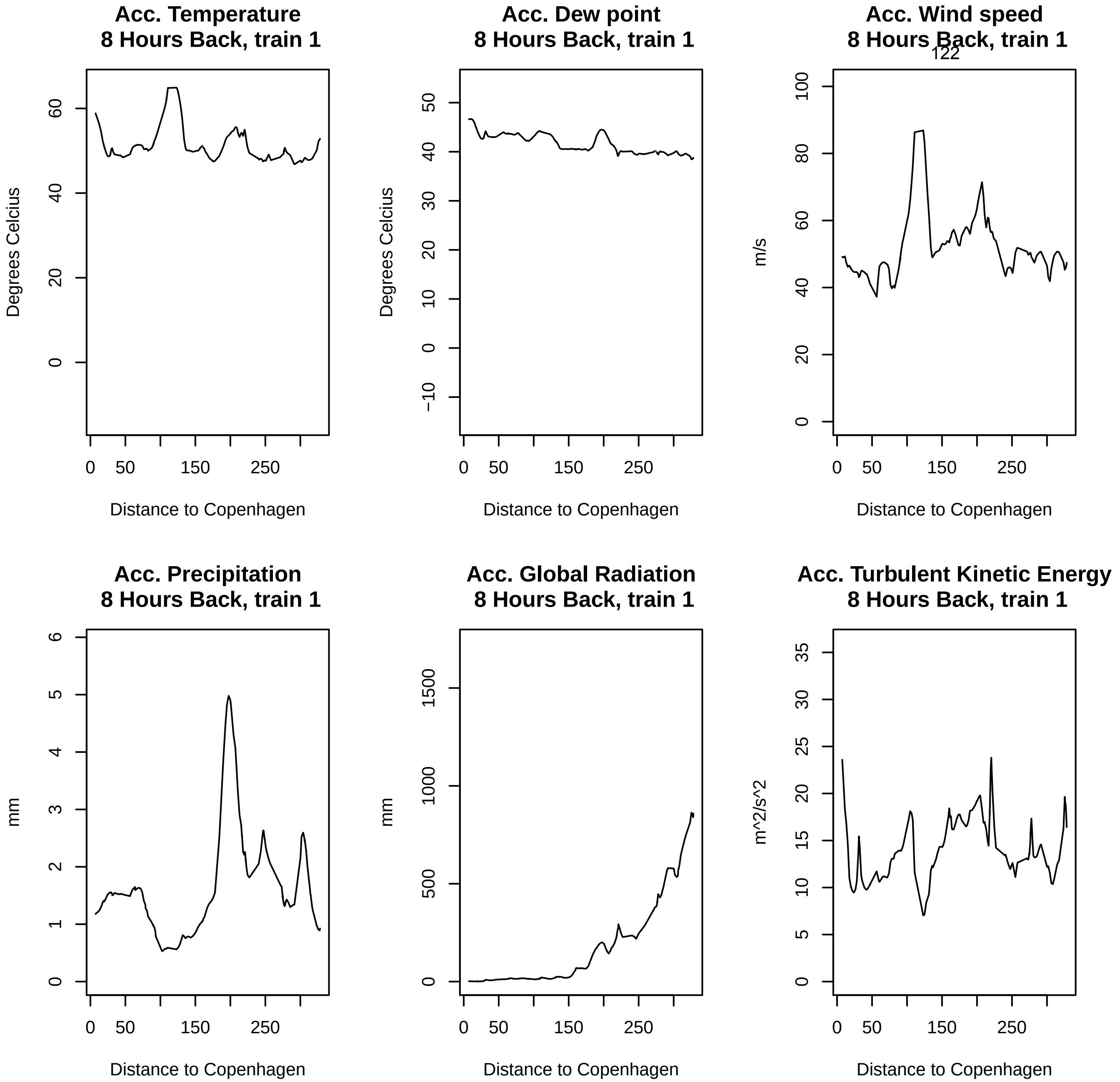

Acc. Temperature
3 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 1
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 1
m^2/s^2
Distance to Copenhagen

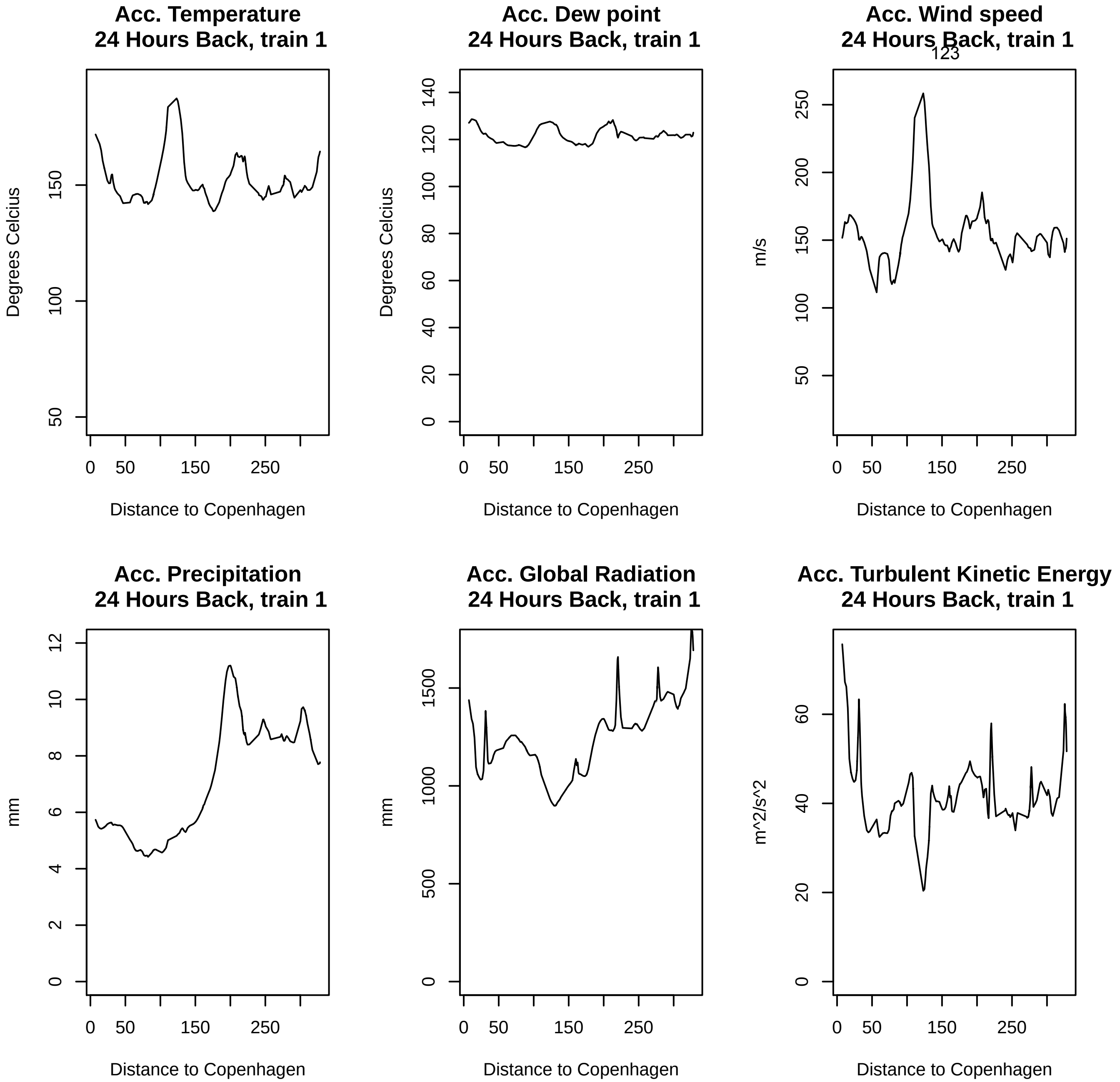

Acc. Temperature
4 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 1
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 1
m^2/s^2
Distance to Copenhagen

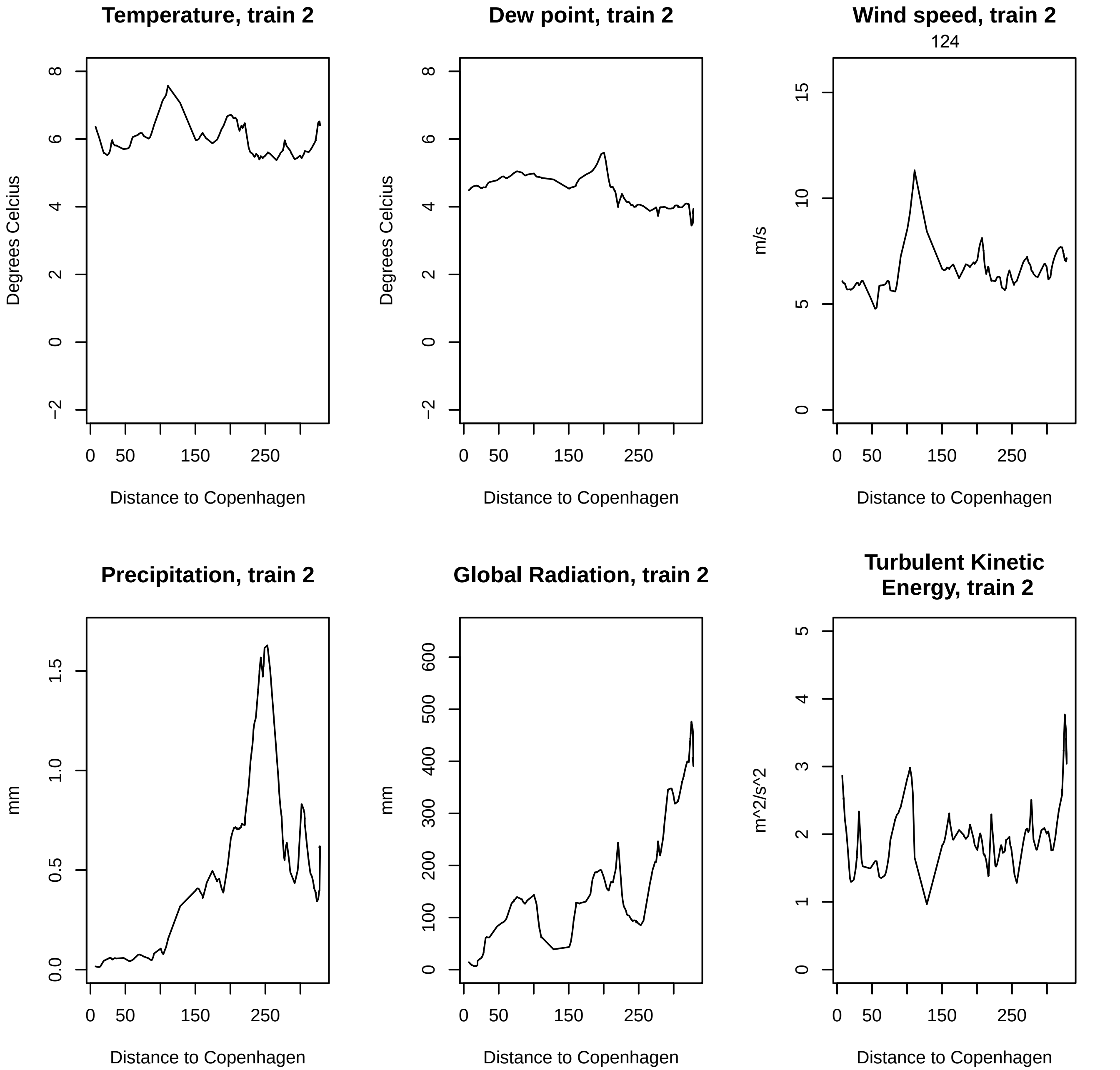

Acc. Temperature
5 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 1
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 1
m^2/s^2
Distance to Copenhagen

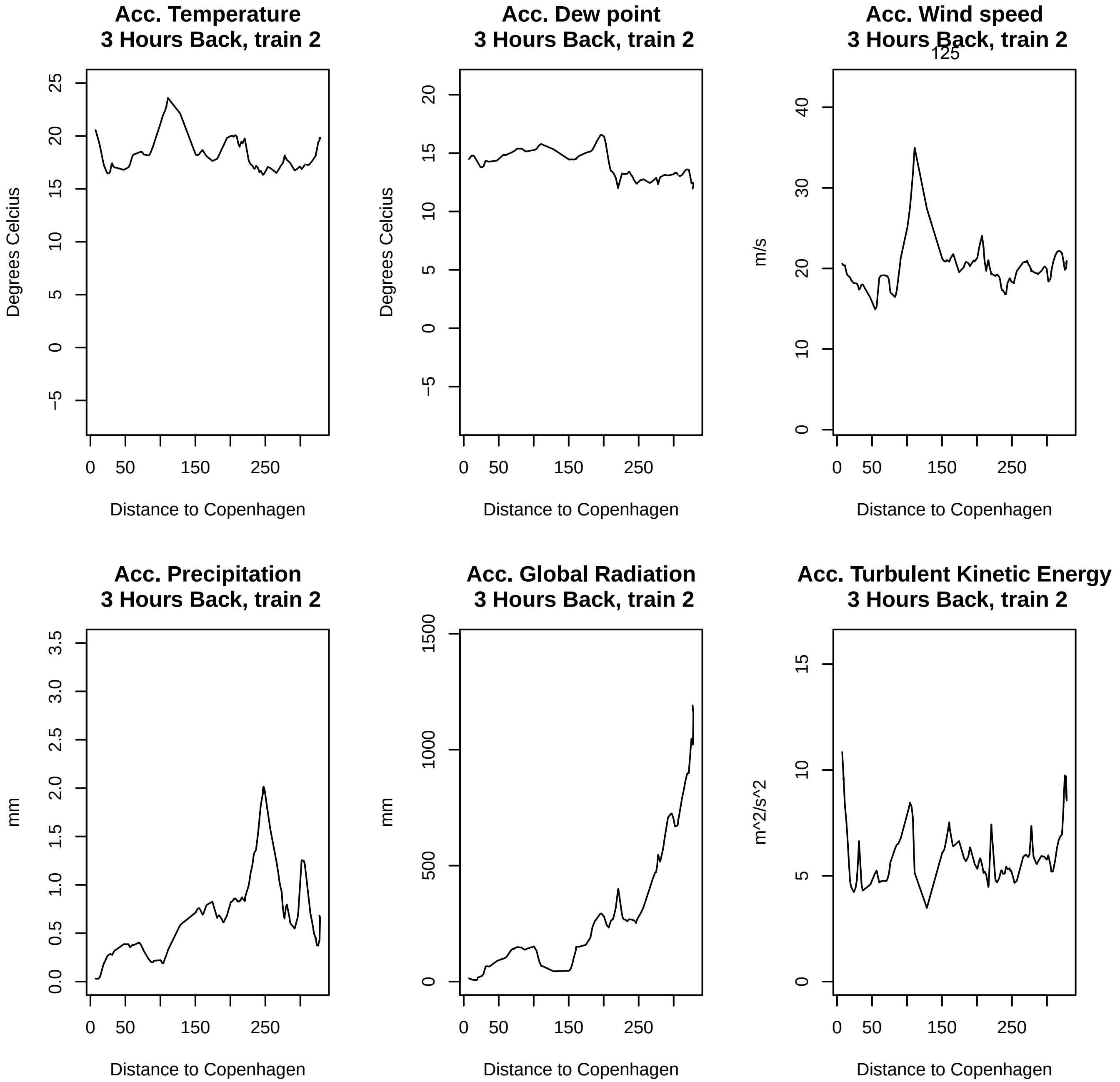

Acc. Temperature
6 Hours Back, train 1
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 1
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 1
120
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 1
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 1
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 1
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

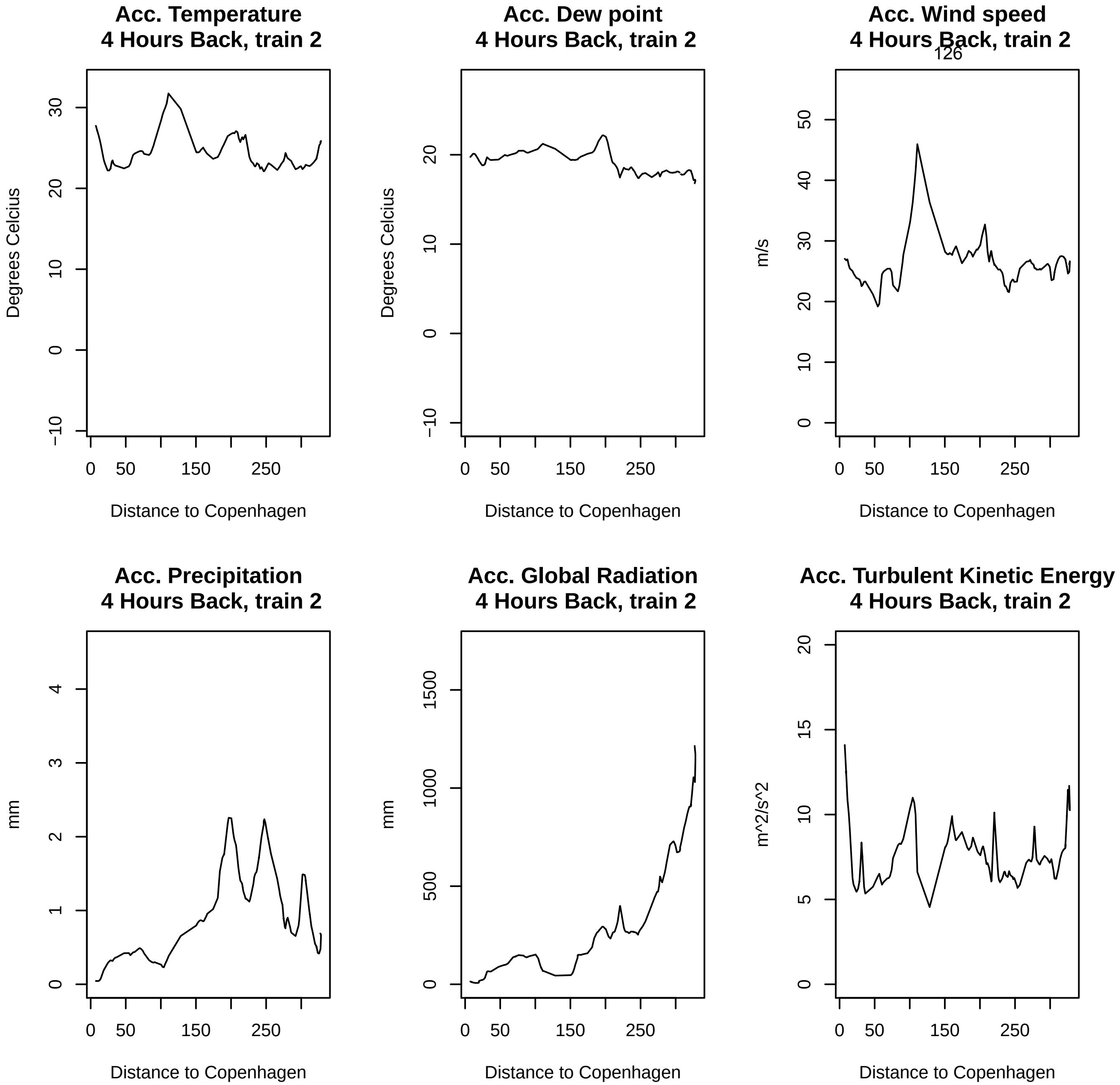

Acc. Temperature
7 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 1
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 1
m^2/s^2
Distance to Copenhagen

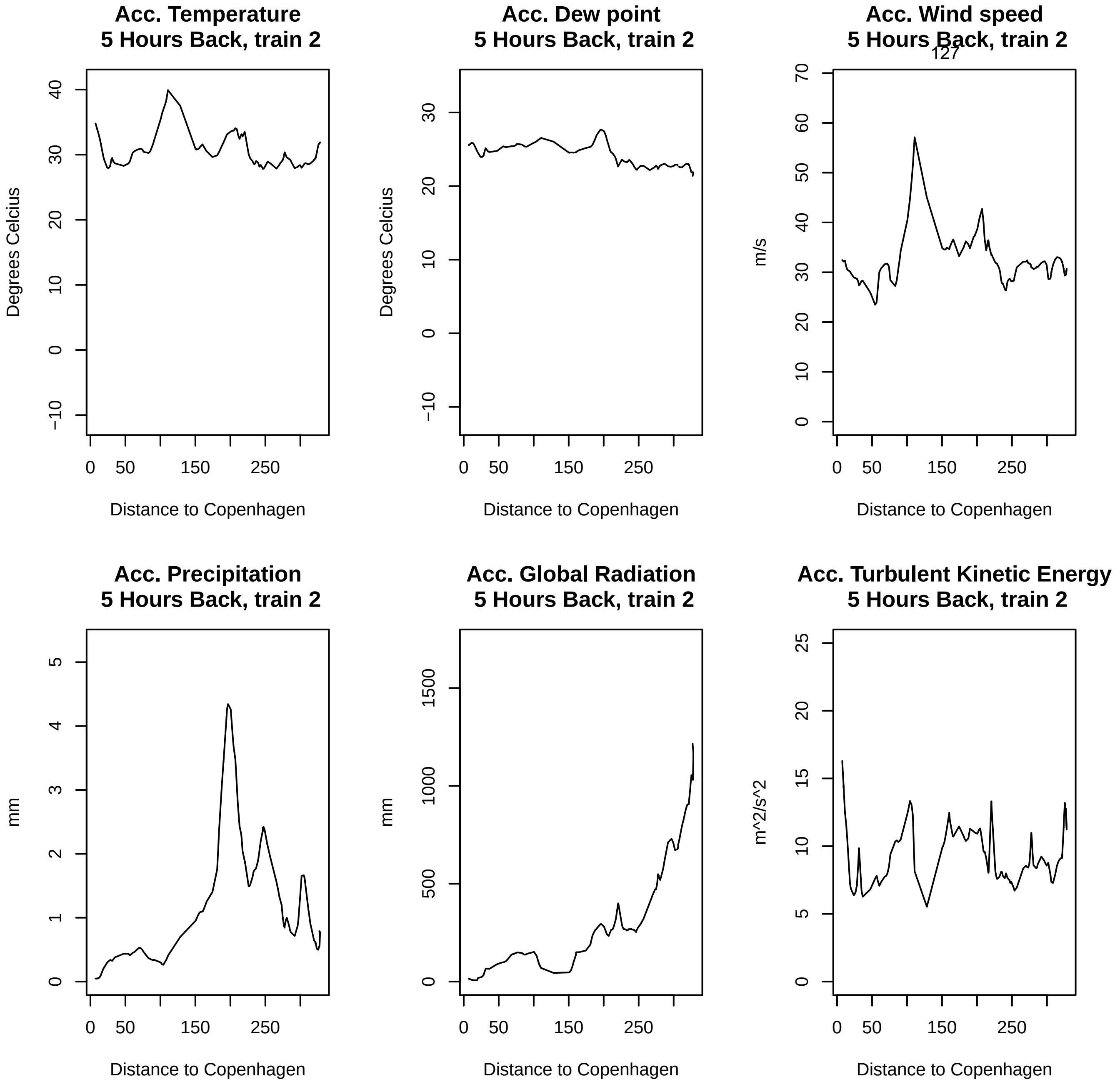

Acc. Temperature
8 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 1
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 1
122
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 1
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 1
m^2/s^2
Distance to Copenhagen

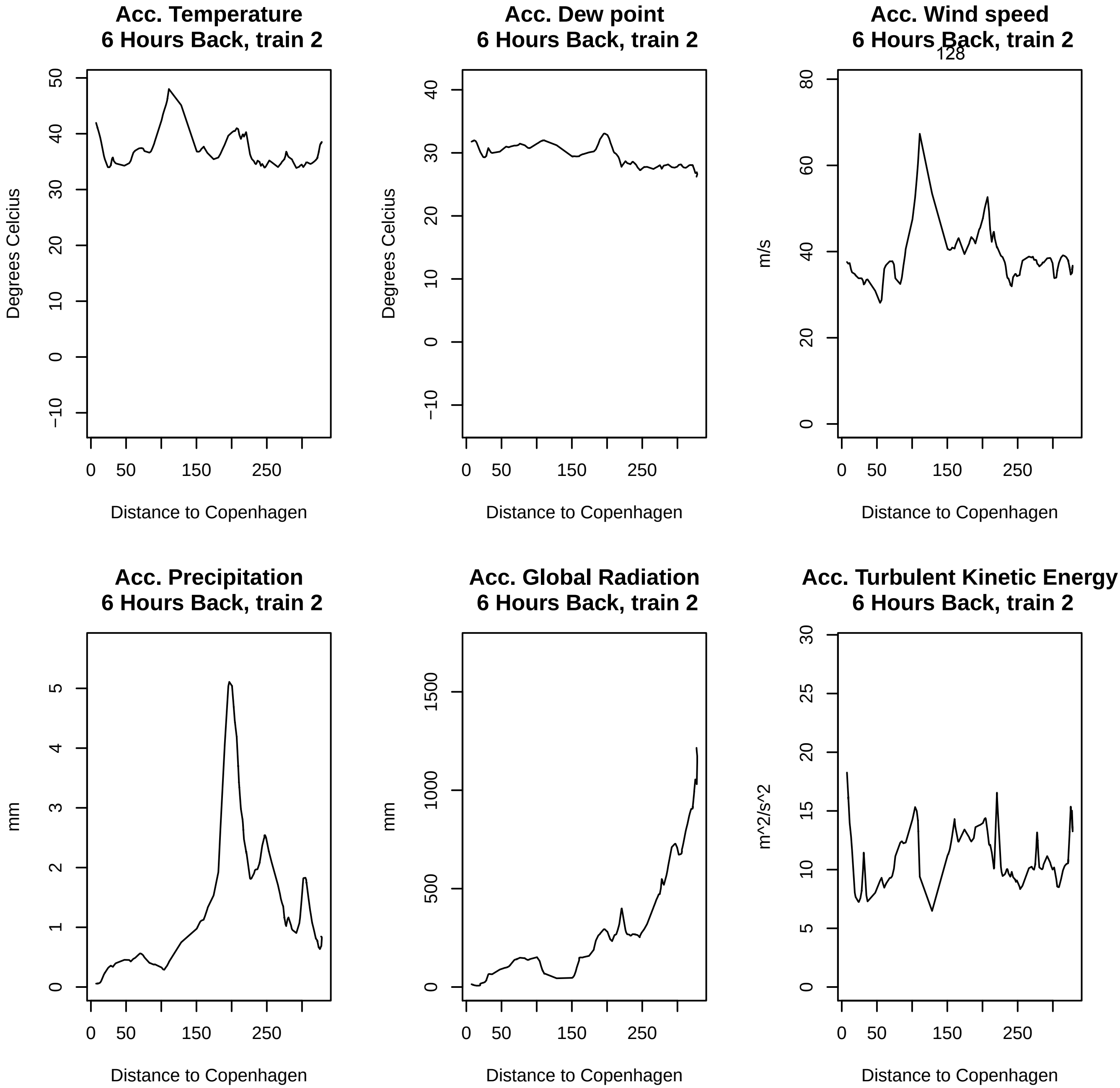

Acc. Temperature
24 Hours Back, train 1
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 1
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 1
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 1
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 1
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 1
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

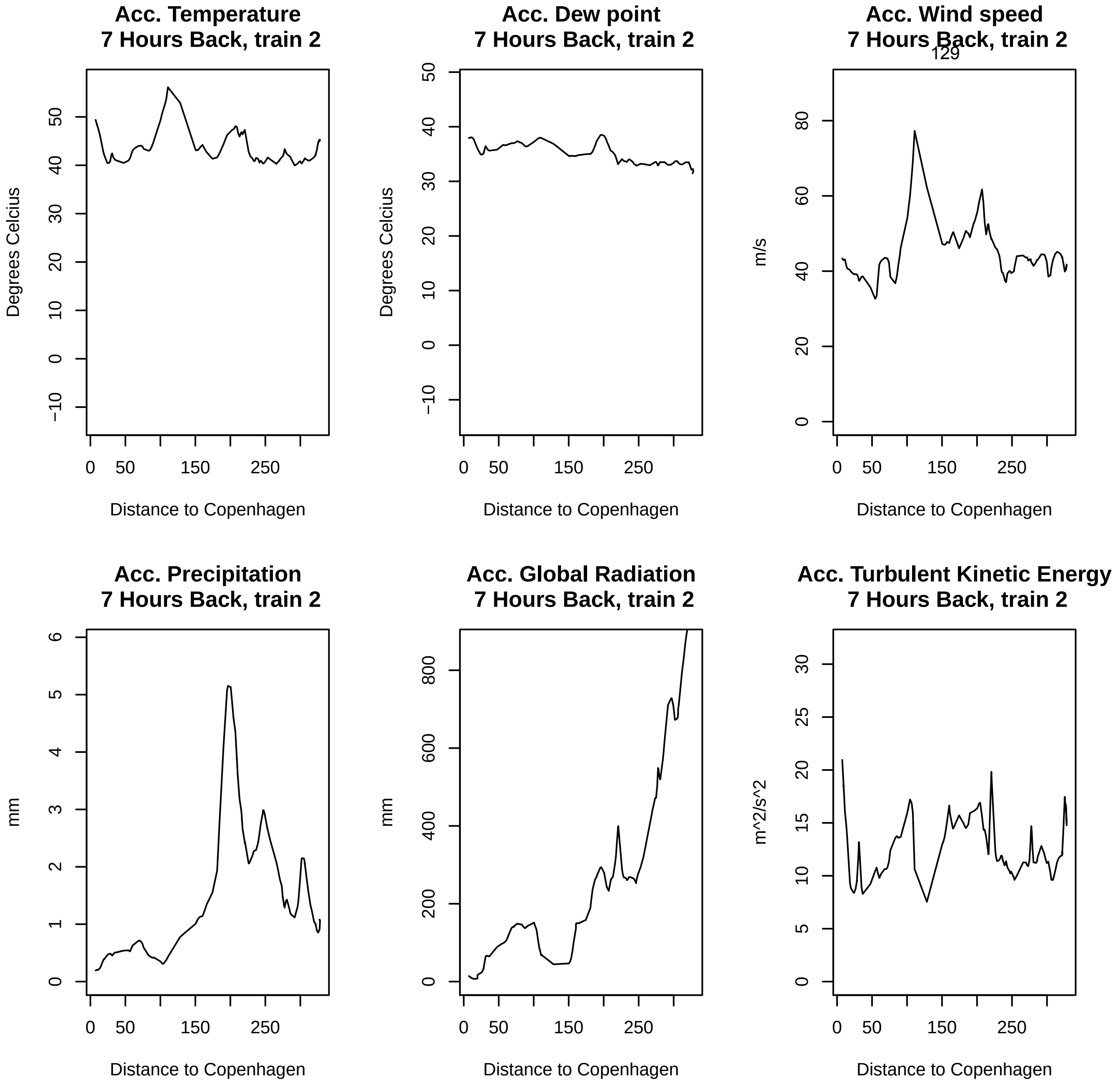

Temperature, train 2
Degrees Celcius
Distance to Copenhagen
Dew point, train 2
Degrees Celcius
Distance to Copenhagen
Wind speed, train 2
m/s
Distance to Copenhagen
Precipitation, train 2
mm
Distance to Copenhagen
Global Radiation, train 2
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 2
m^2/s^2
Distance to Copenhagen

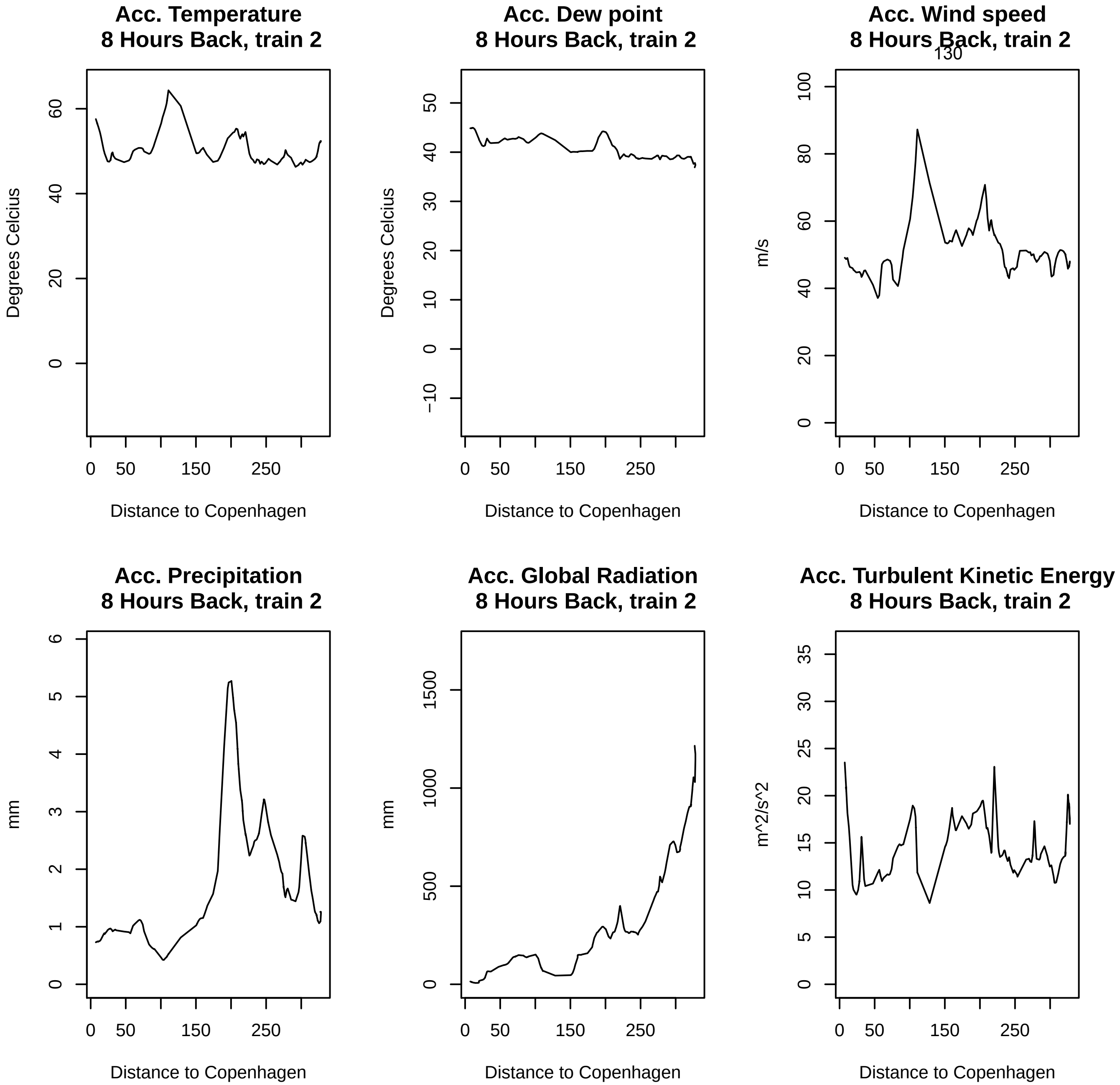

Acc. Temperature
3 Hours Back, train 2
Degrees Celcius
−5 0 5 10 15 20 25
0 50 150 250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 2
Degrees Celcius
−5 0 5 10 15 20
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 2
125
m/s
0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 2
mm
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 2
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 2
m^2/s^2
0 5 10 15
0 50 150 250
Distance to Copenhagen

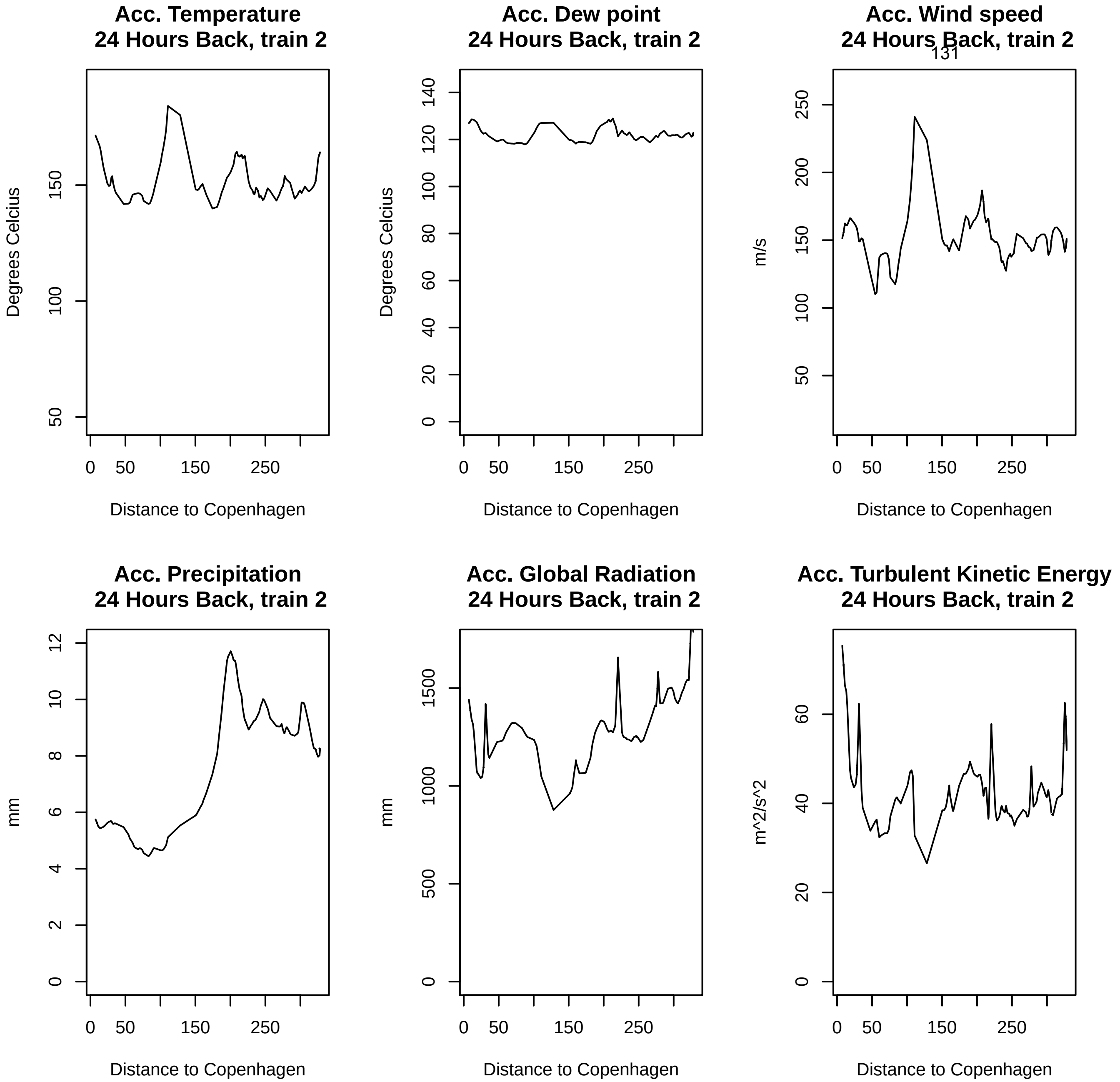

Acc. Temperature
4 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 2
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 2
m^2/s^2
Distance to Copenhagen

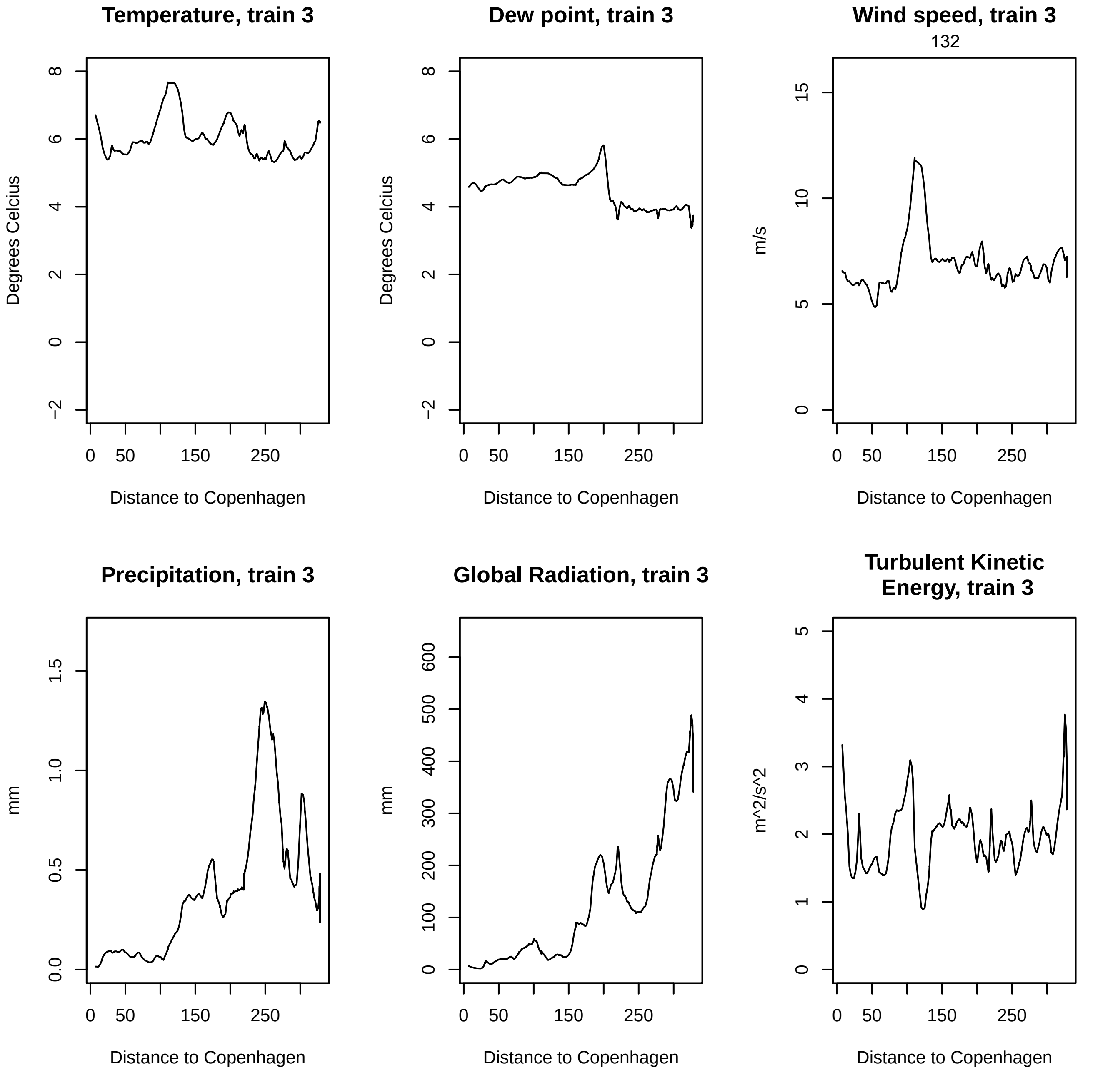

Acc. Temperature
5 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 2
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 2
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 2
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 2
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 2
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 2
m^2/s^2
Distance to Copenhagen

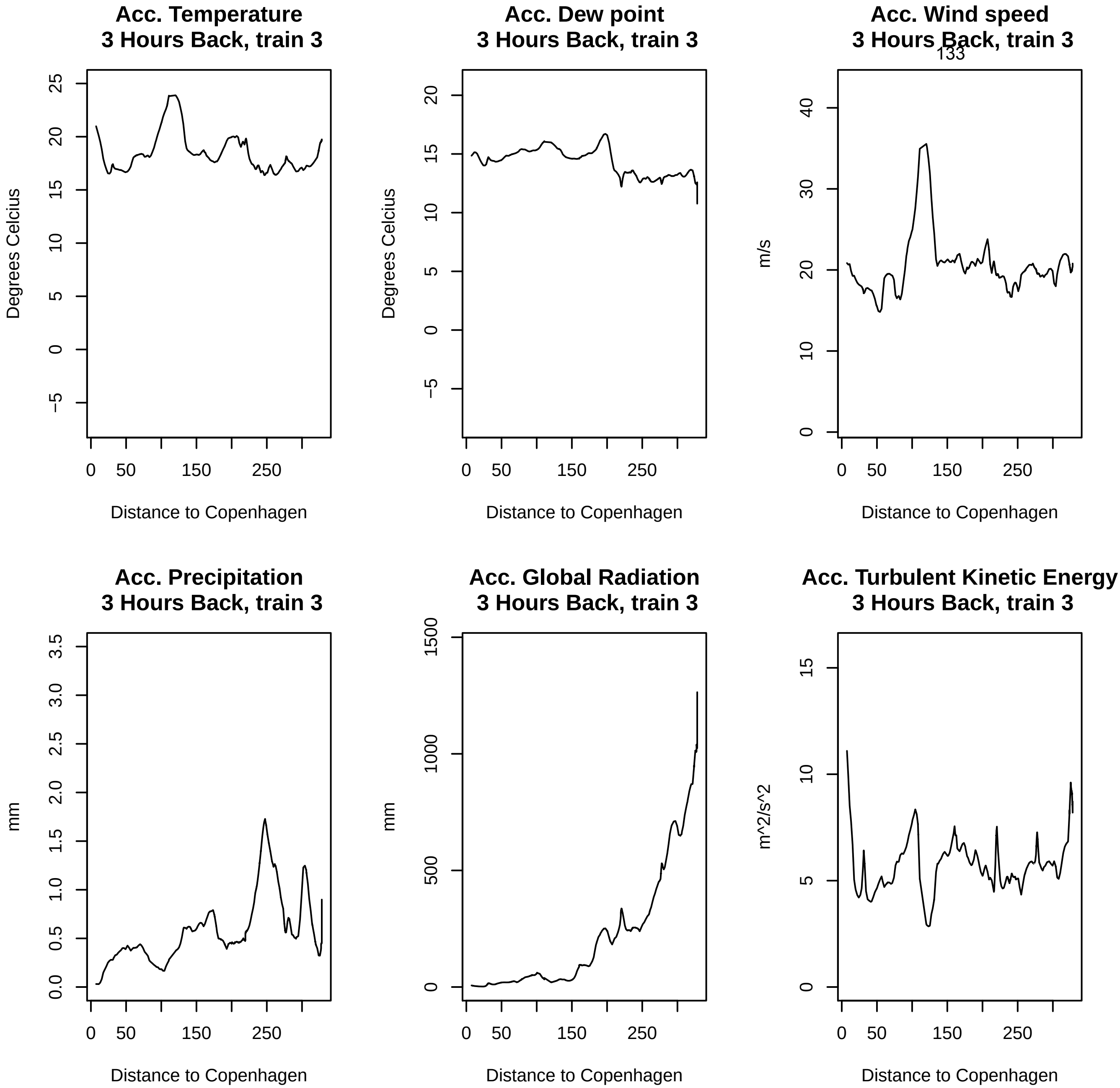

Acc. Temperature
7 Hours Back, train 2
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 2
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 2
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 2
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 2
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 2
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

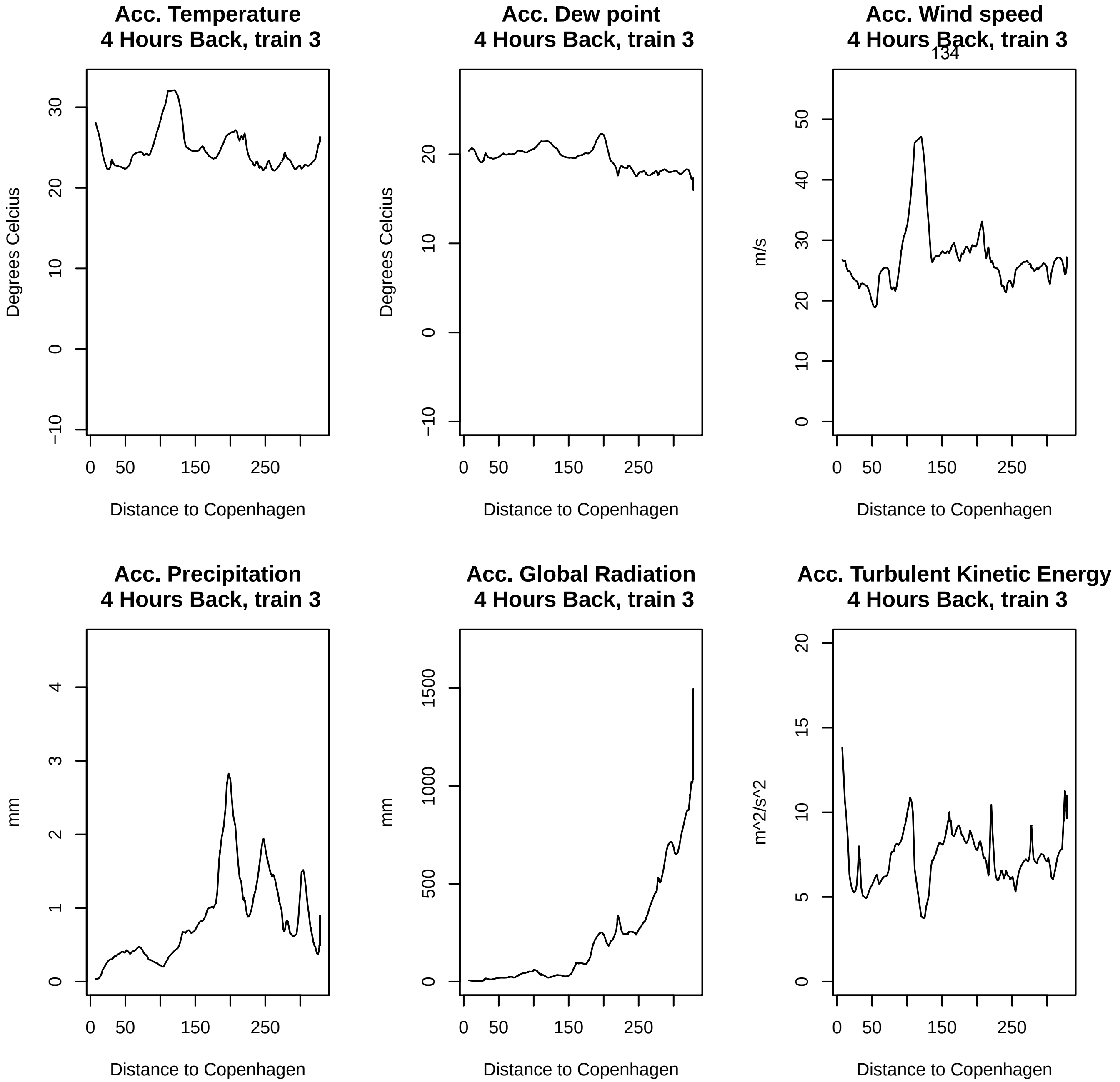

Acc. Temperature
8 Hours Back, train 2
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 2
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 2
130
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 2
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 2
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 2
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen

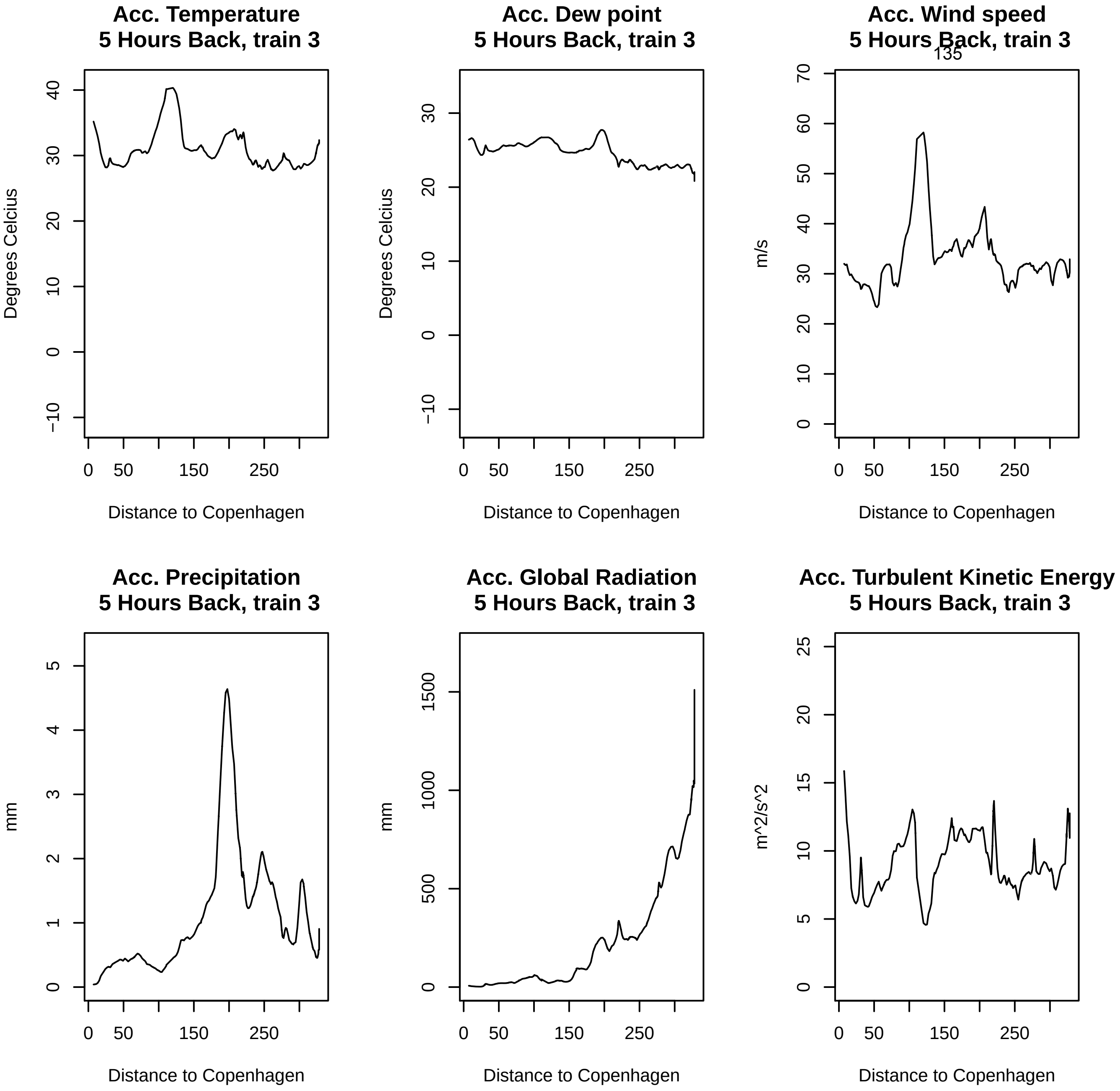

Acc. Temperature
24 Hours Back, train 2
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 2
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 2
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 2
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 2
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 2
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen



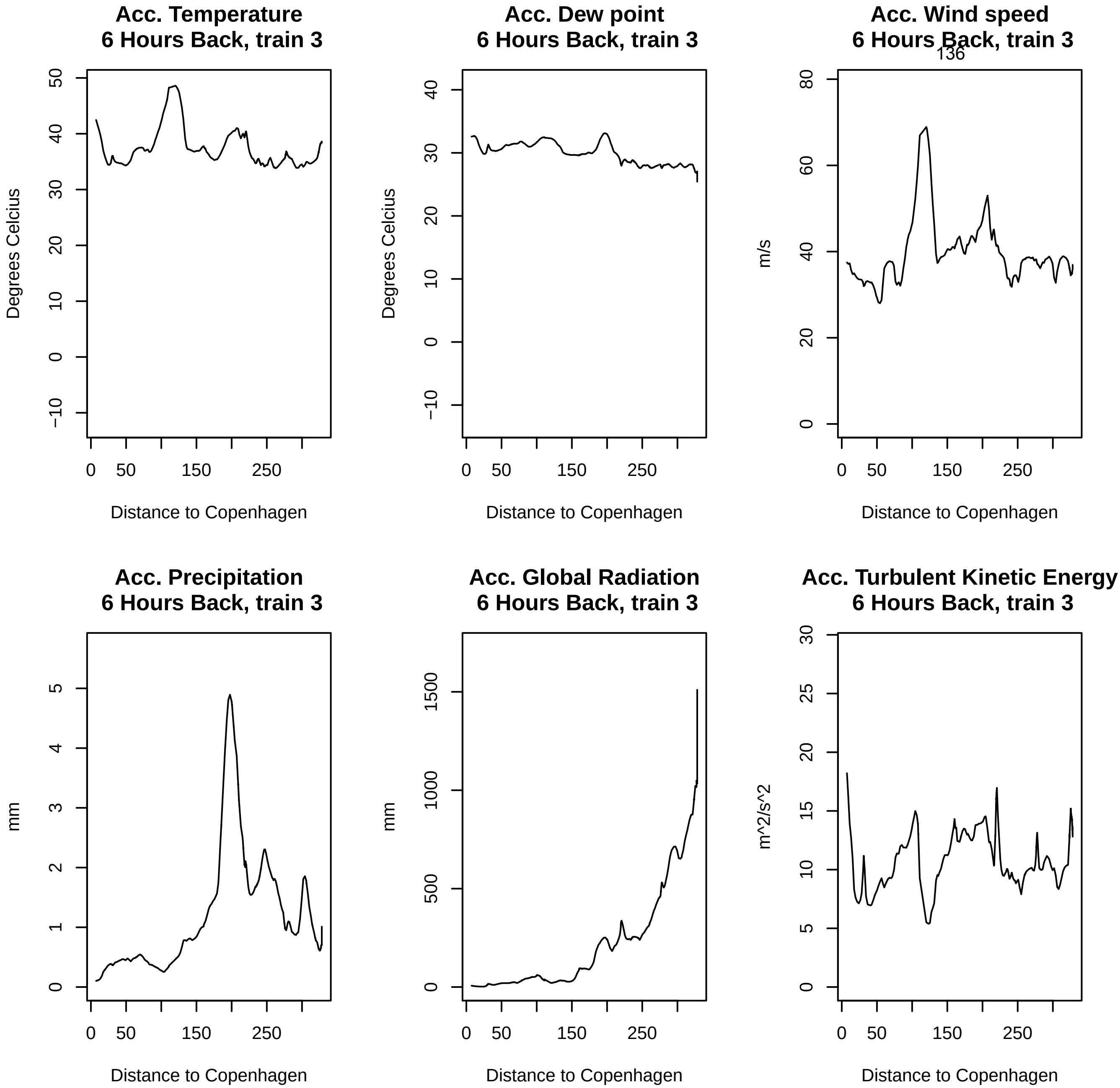
Temperature, train 3
Degrees Celcius
Distance to Copenhagen
Dew point, train 3
Degrees Celcius
Distance to Copenhagen
Wind speed, train 3
132
m/s
Distance to Copenhagen
Precipitation, train 3
mm
Distance to Copenhagen
Global Radiation, train 3
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 3
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 3
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 3
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 3
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 3
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 3
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 3
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 3
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
0
50
150
250
Acc. Dew point
4 Hours Back, train 3
Degrees Celcius
−10
0
10
20
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 3
m/s
0
10
20
30
40
50
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 3
mm
0
1
2
3
4
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 3
mm
0
500
1000
1500
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 3
m^2/s^2
0
5
10
15
20
Distance to Copenhagen



Acc. Temperature
5 Hours Back, train 3
Degrees Celcius
−10 0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 3
Degrees Celcius
−10 0 10 20 30
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 3
m/s
0 10 20 30 40 50 60 70
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 3
mm
0 1 2 3 4 5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 3
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 3
m^2/s^2
0 5 10 15 20 25
0 50 150 250
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 3
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 3
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 3
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 3
mm
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1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 3
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 3
m^2/s^2
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25
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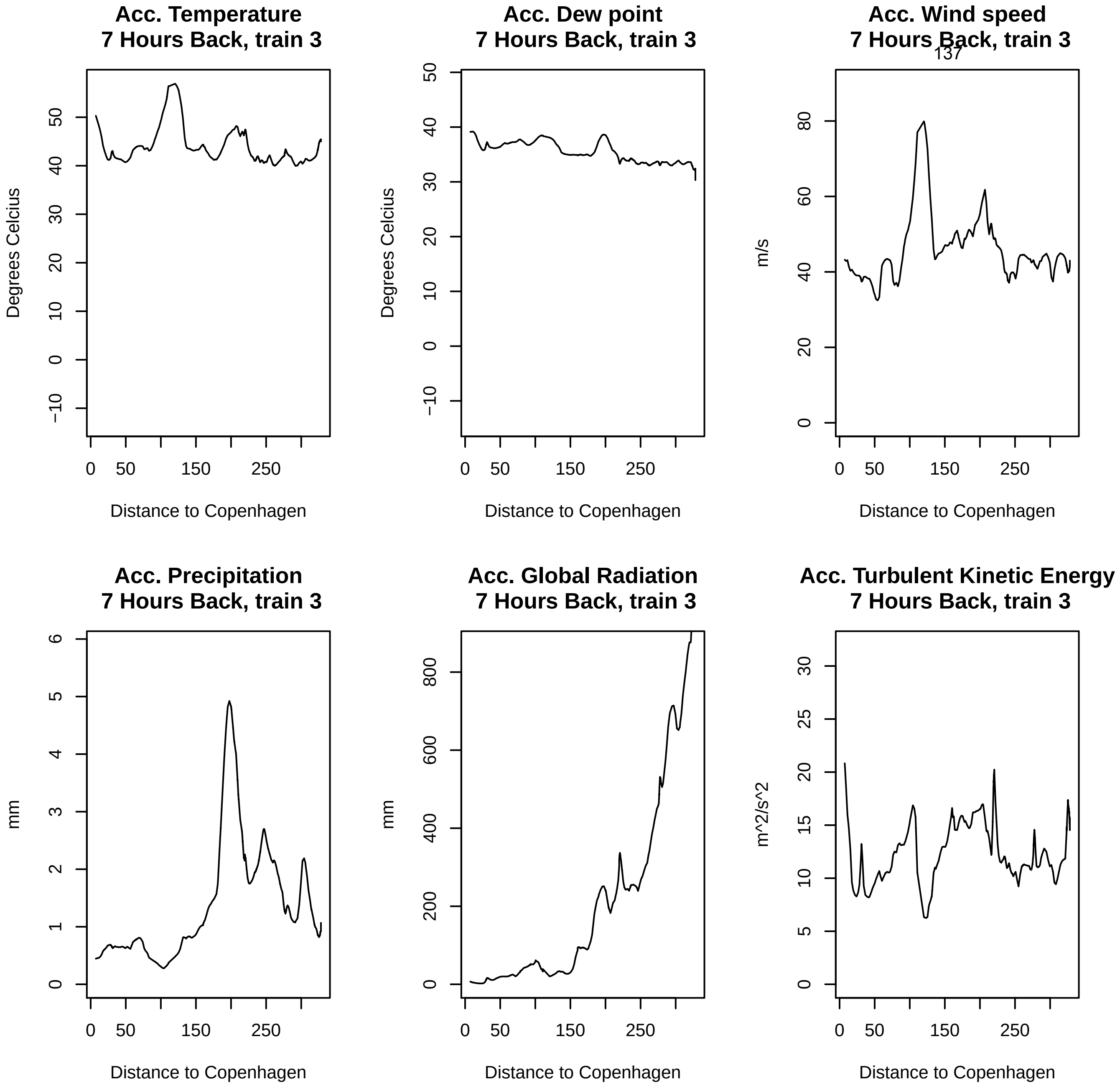
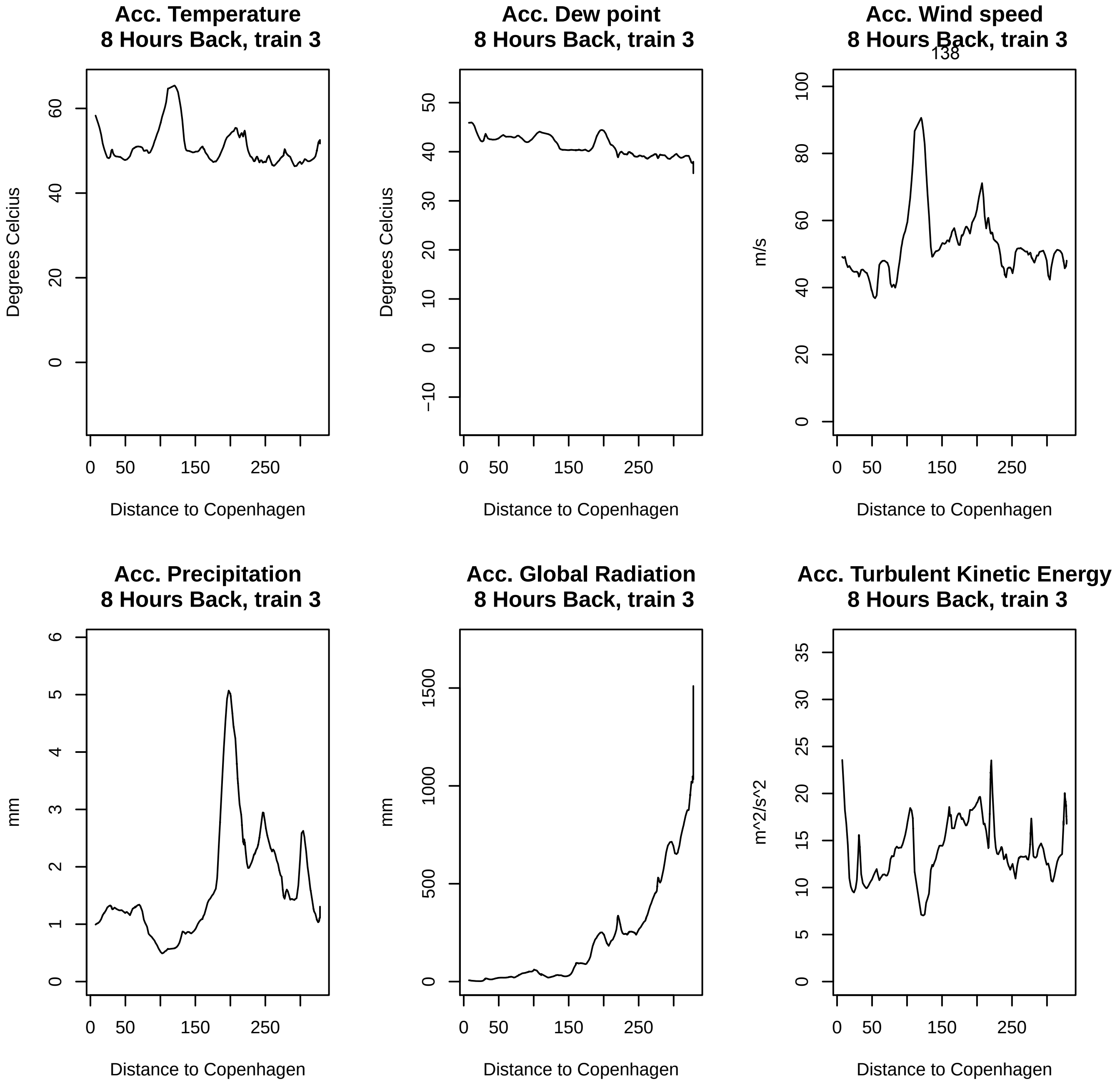
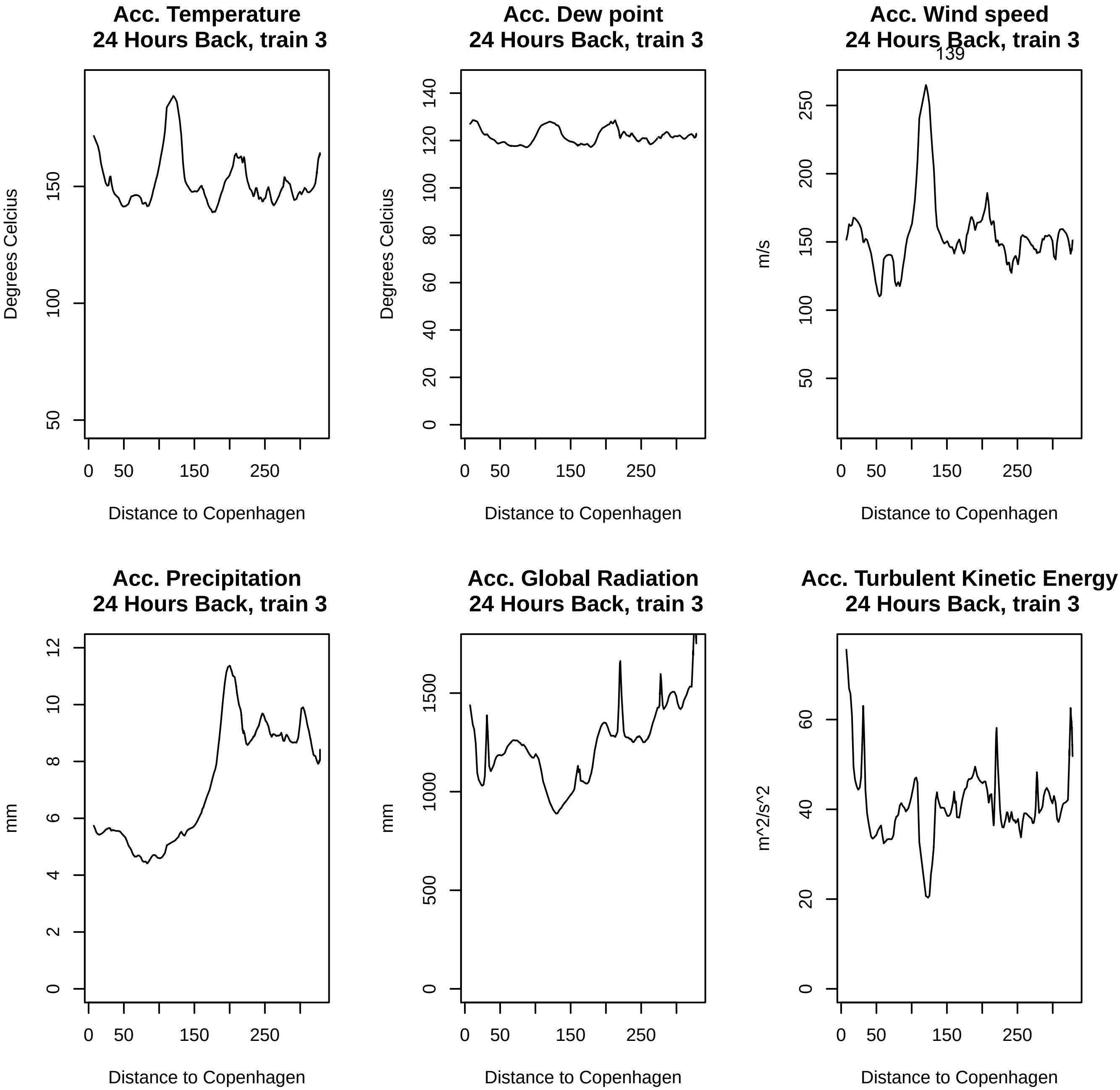
0
50
150
250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 3
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 3
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 3
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 3
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 3
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 3
m^2/s^2
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 3
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 3
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 3
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 3
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 3
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 3
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen


Acc. Temperature
24 Hours Back, train 3
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 3
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 3
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 3
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 3
mm
0
500
1000
1500
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50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 3
m^2/s^2
0
20
40
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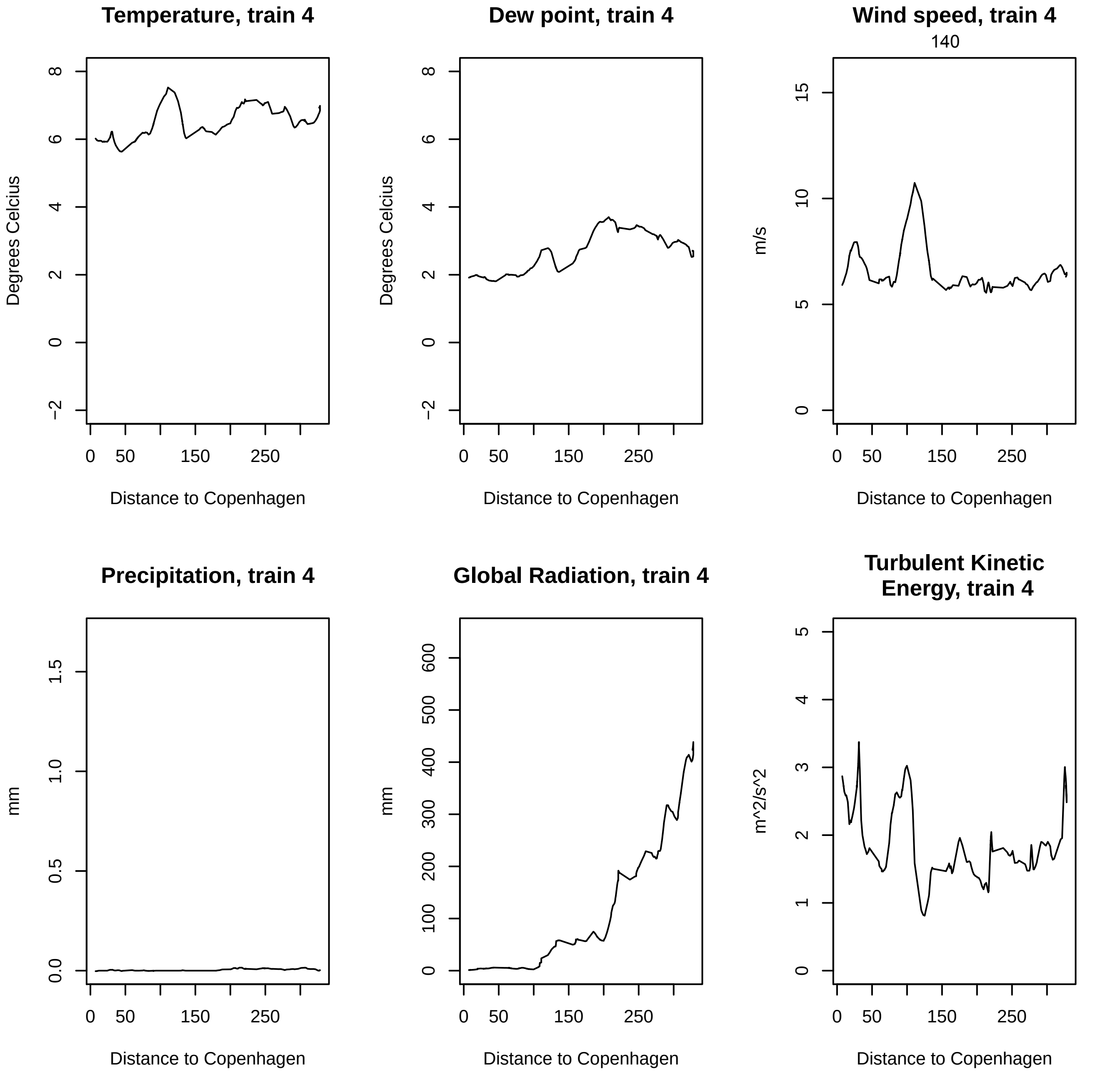
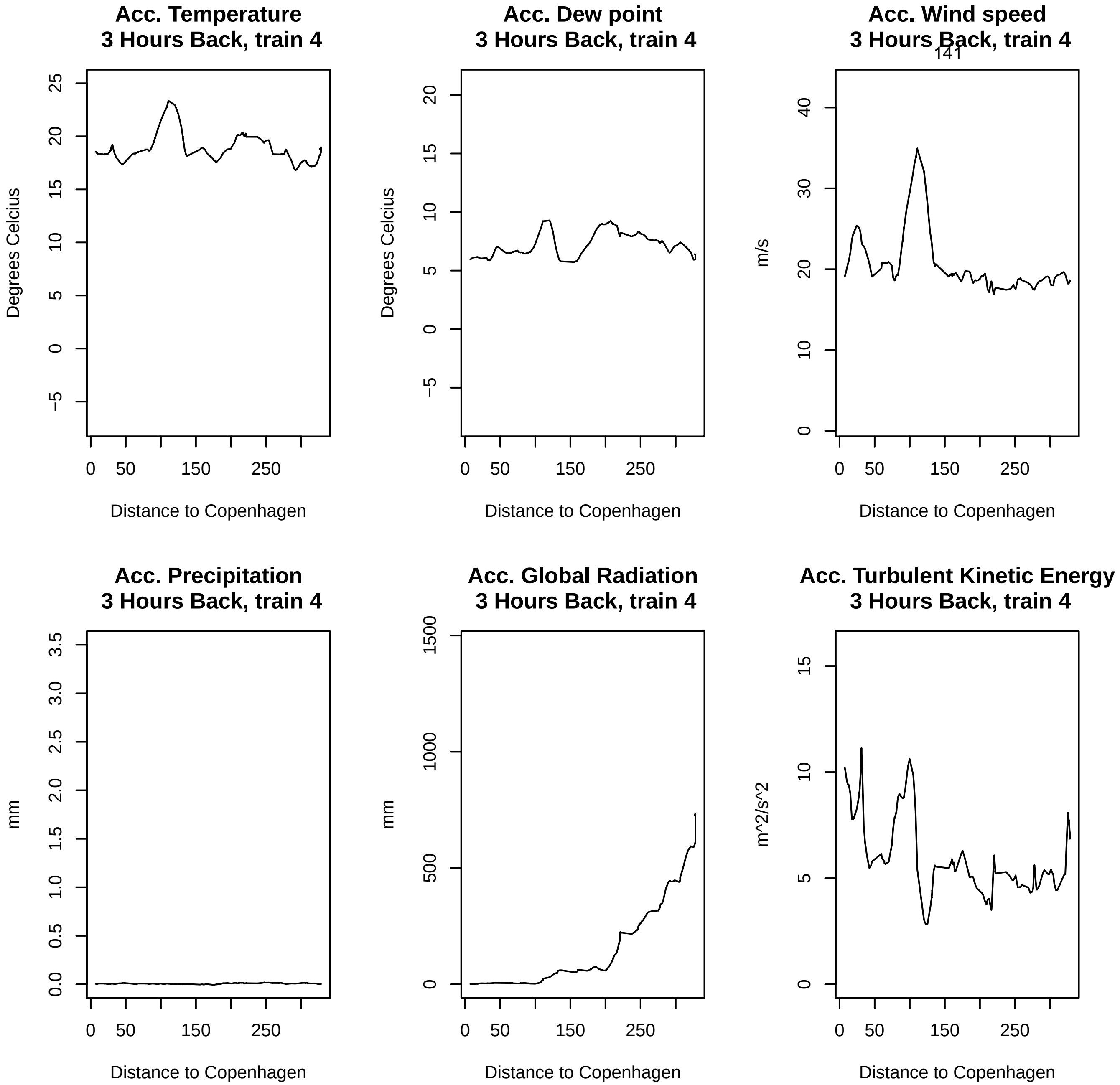
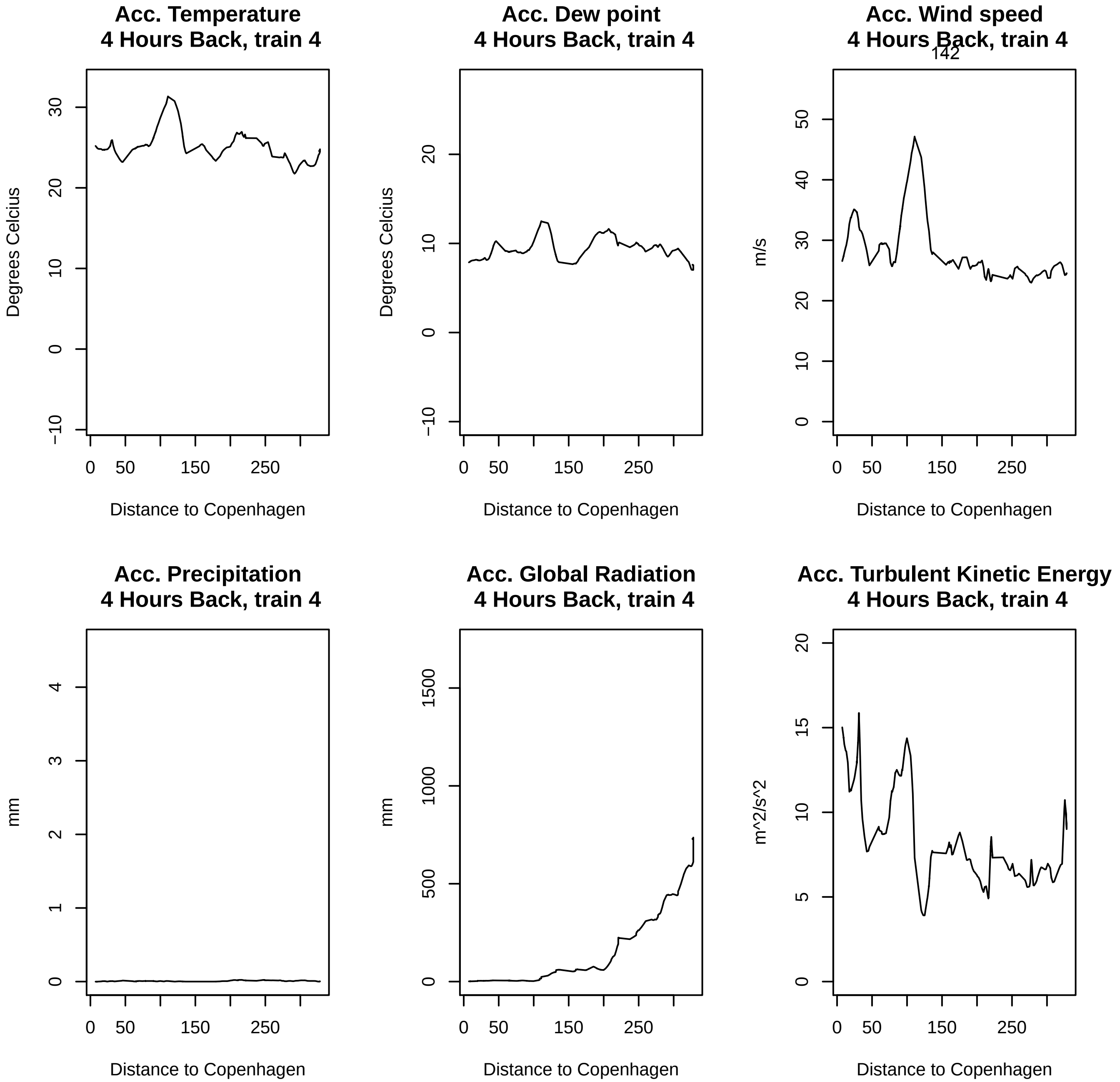
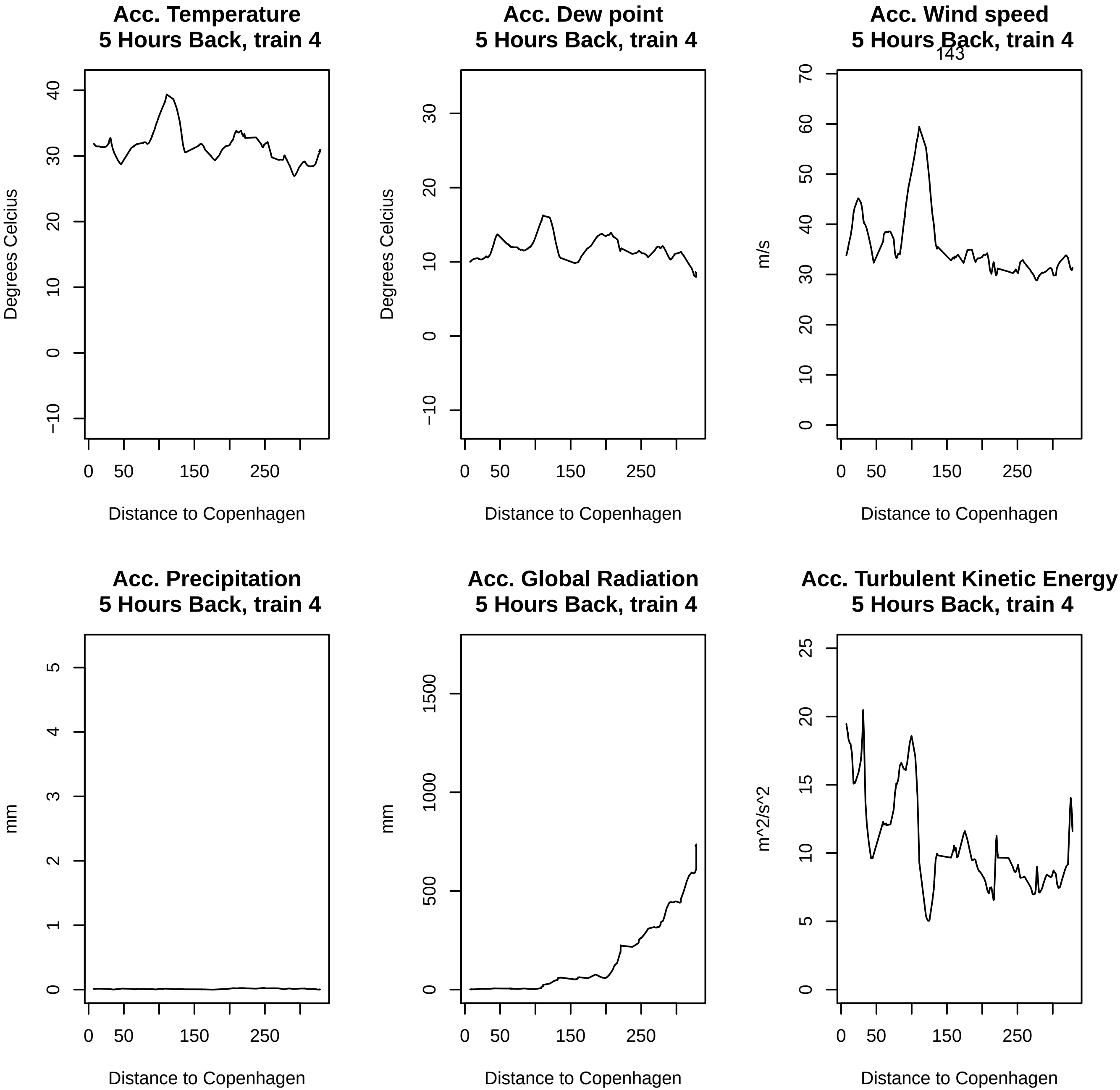
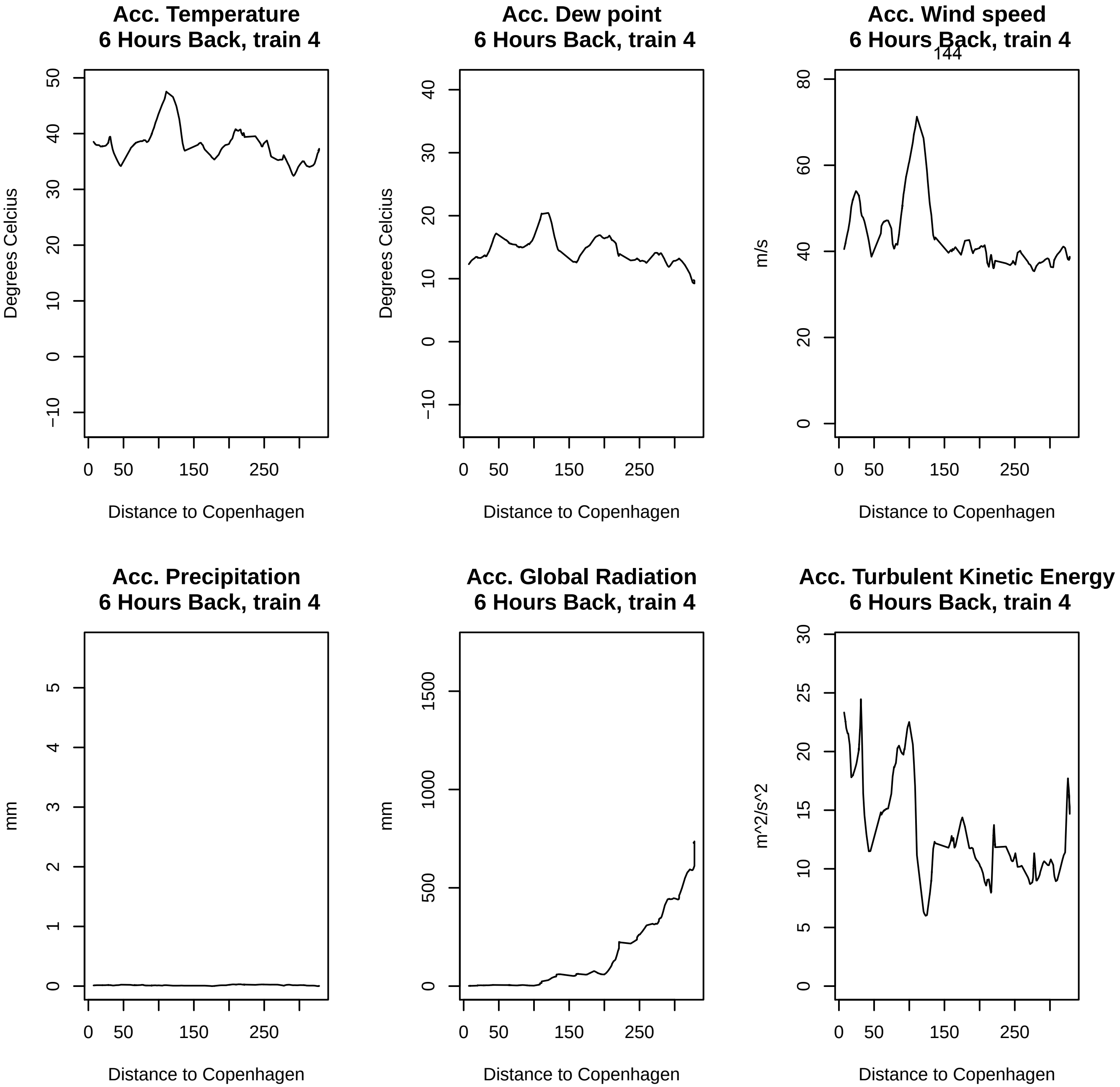
0
50
150
250
Distance to Copenhagen

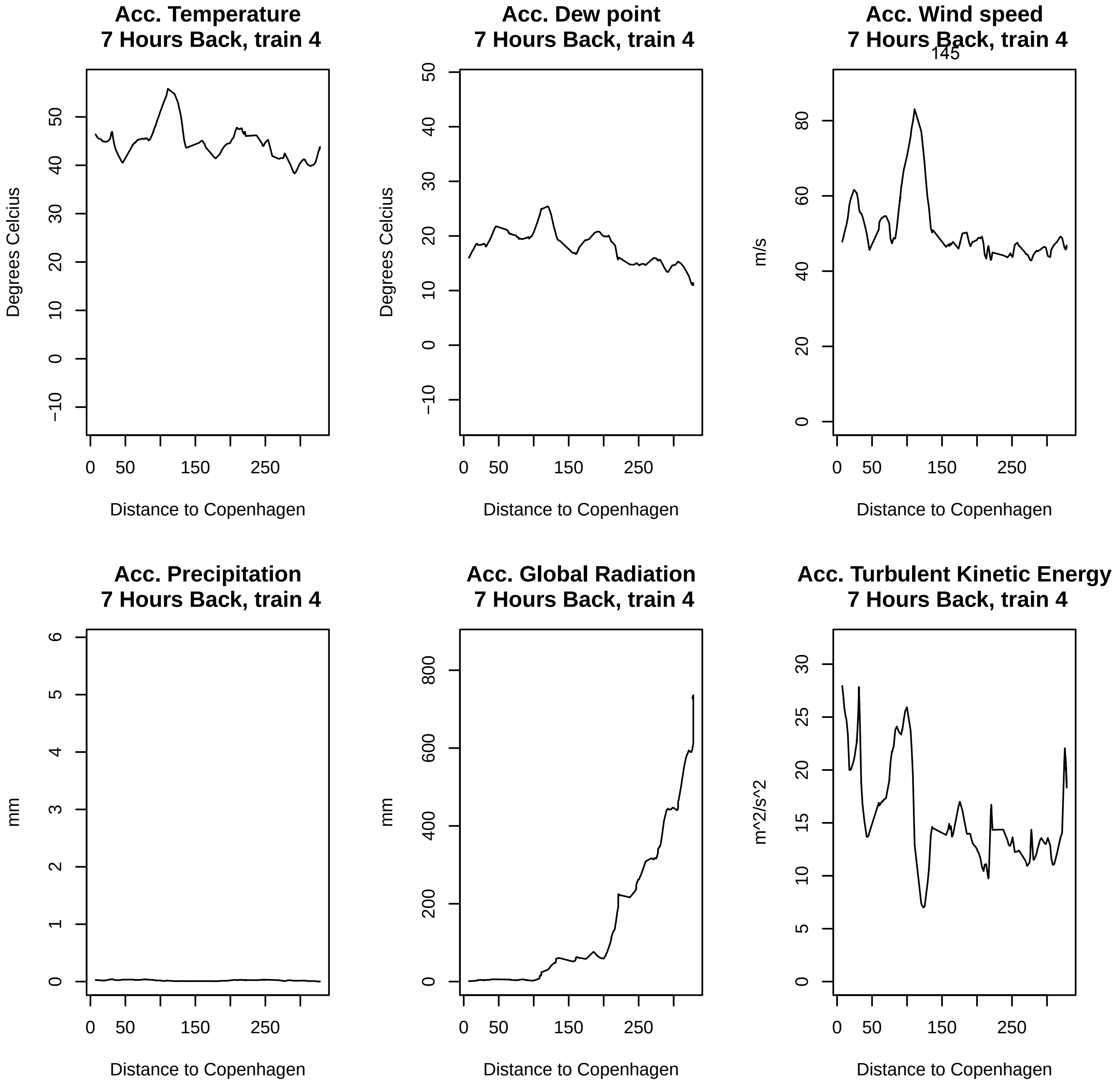

Temperature, train 4
Degrees Celcius
Dew point, train 4
Degrees Celcius
Wind speed, train 4
m/s
Precipitation, train 4
mm
Global Radiation, train 4
mm
Turbulent Kinetic Energy, train 4
m^2/s^2
Distance to Copenhagen
0 50 150 250

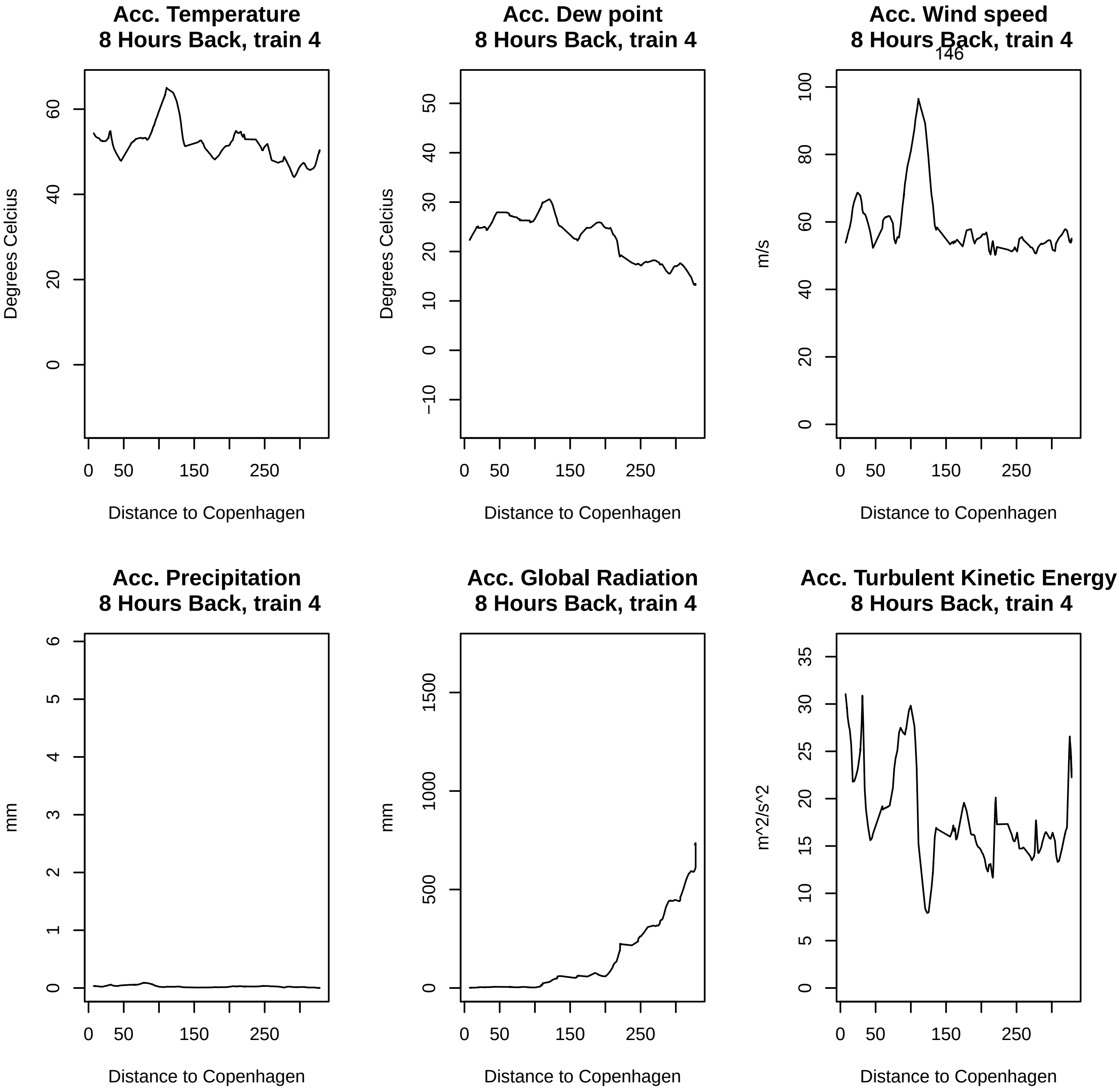

Acc. Temperature
3 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 4
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 4
m^2/s^2
Distance to Copenhagen

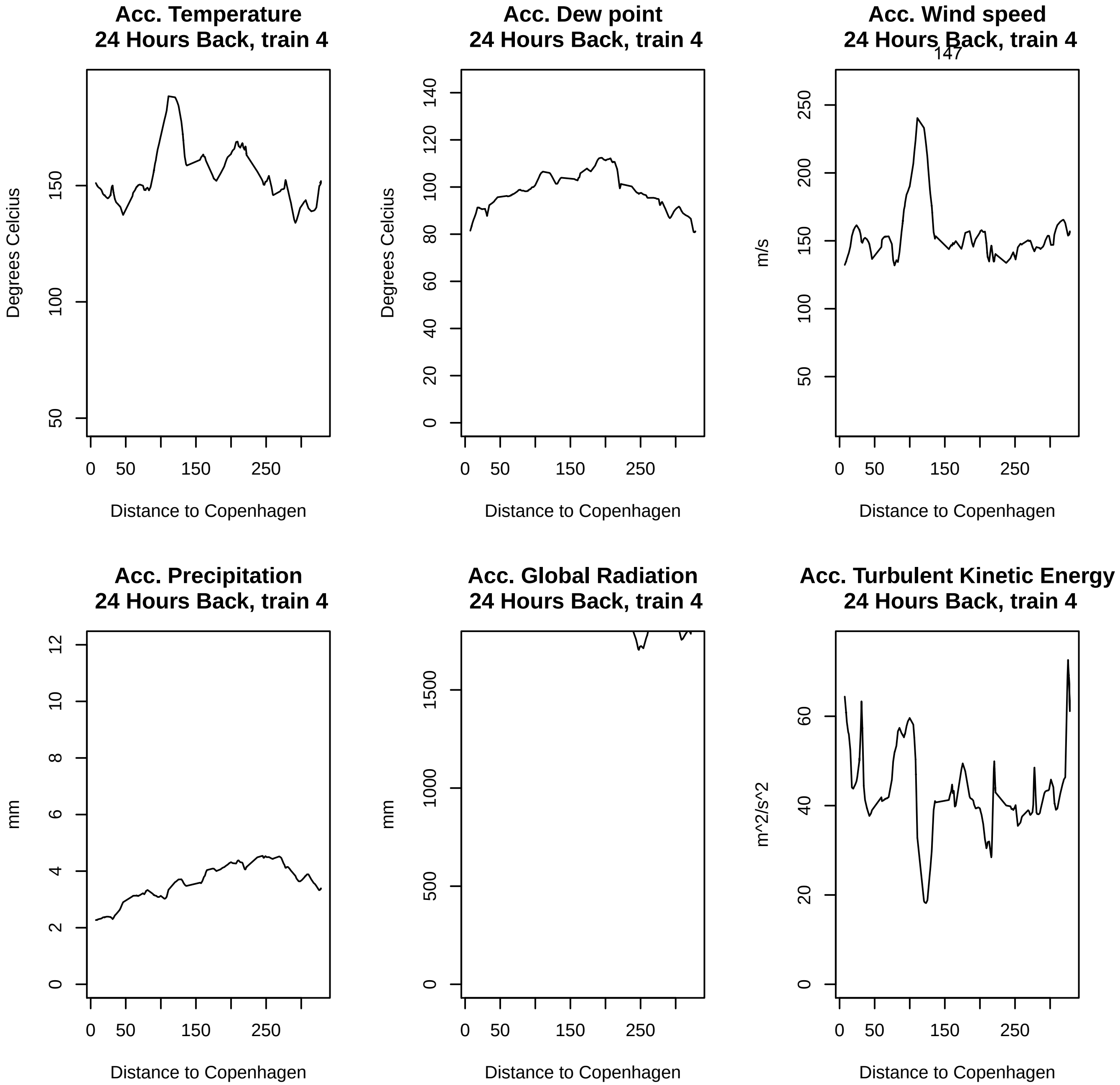

Acc. Temperature
4 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 4
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 4
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 4
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 4
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 4
m/s
0
10
20
30
40
50
60
70
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 4
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 4
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 4
m^2/s^2
0
5
10
15
20
25
0
50
150
250
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 4
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 4
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 4
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 4
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 4
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 4
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
−10
0
10
20
30
40
50
0
50
150
250
Acc. Dew point
7 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
−10
0
10
20
30
40
50
Acc. Wind speed
7 Hours Back, train 4
m/s
Distance to Copenhagen
0
20
40
60
80
Acc. Precipitation
7 Hours Back, train 4
mm
Distance to Copenhagen
0
1
2
3
4
5
6
Acc. Global Radiation
7 Hours Back, train 4
mm
Distance to Copenhagen
0
200
400
600
800
Acc. Turbulent Kinetic Energy
7 Hours Back, train 4
m^2/s^2
Distance to Copenhagen
0
5
10
15
20
25
30


Acc. Temperature
8 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 4
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 4
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 4
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 4
m^2/s^2
Distance to Copenhagen


Acc. Temperature
24 Hours Back, train 4
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 4
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 4
147
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 4
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 4
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 4
m^2/s^2
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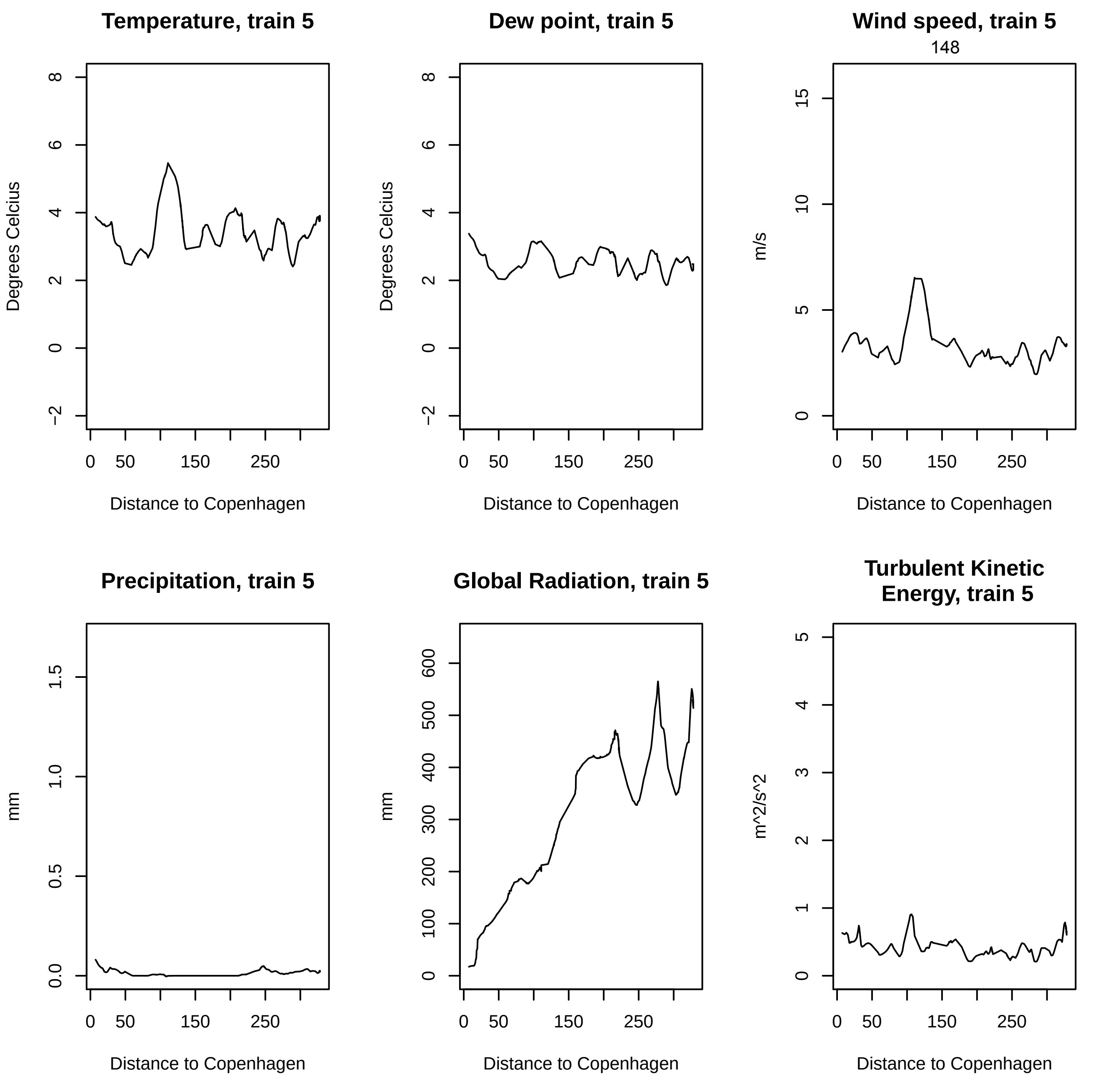
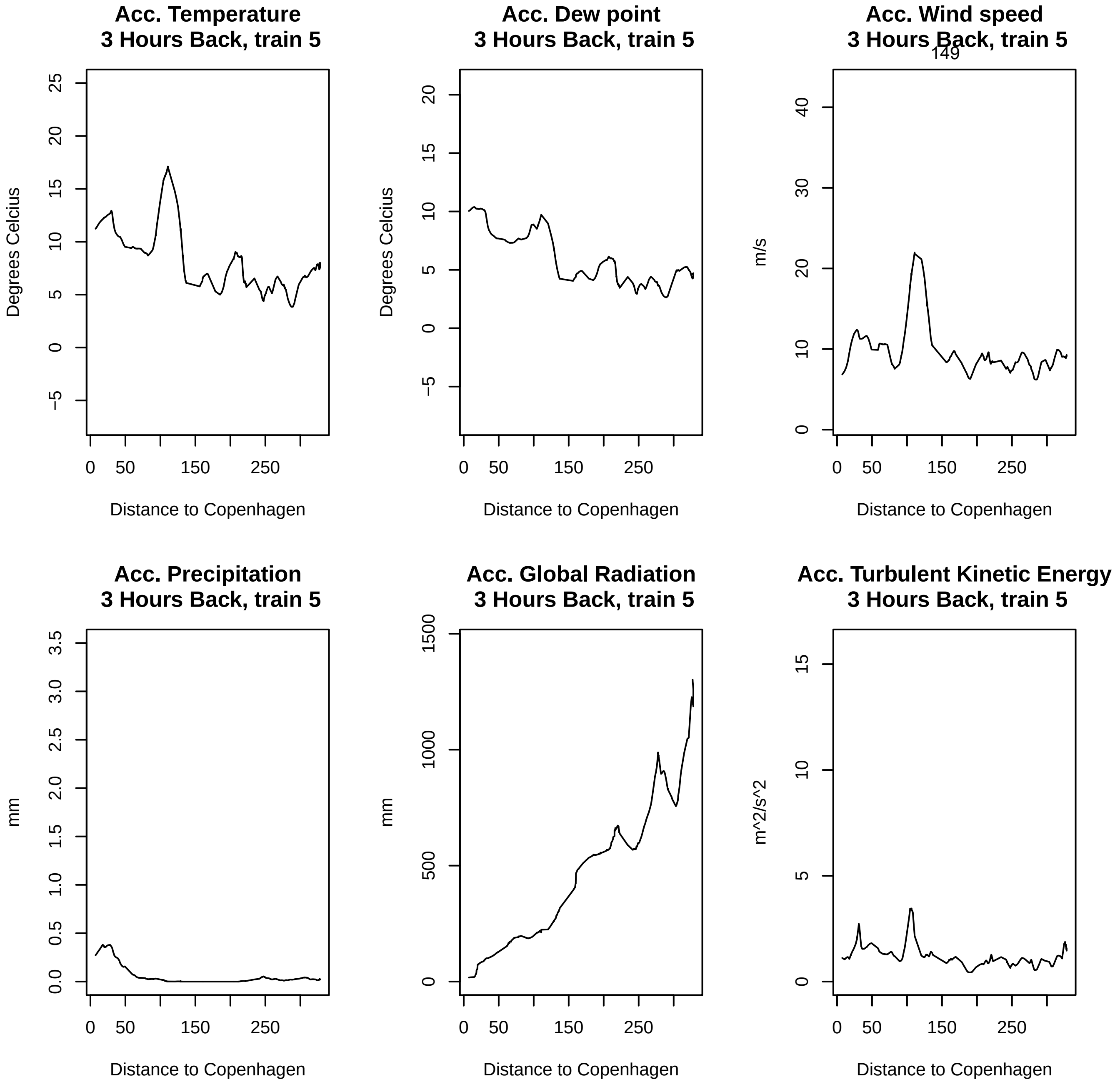
20
40
60
0
50
150
250
Distance to Copenhagen


Temperature, train 5
Degrees Celcius
Distance to Copenhagen
Dew point, train 5
Degrees Celcius
Distance to Copenhagen
Wind speed, train 5
148
m/s
Distance to Copenhagen
Precipitation, train 5
mm
Distance to Copenhagen
Global Radiation, train 5
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 5
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 5
Degrees Celcius
−5
0
5
10
15
20
25
0
50
150
250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 5
Degrees Celcius
−5
0
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10
15
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 5
m/s
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30
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150
250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 5
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 5
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 5
m^2/s^2
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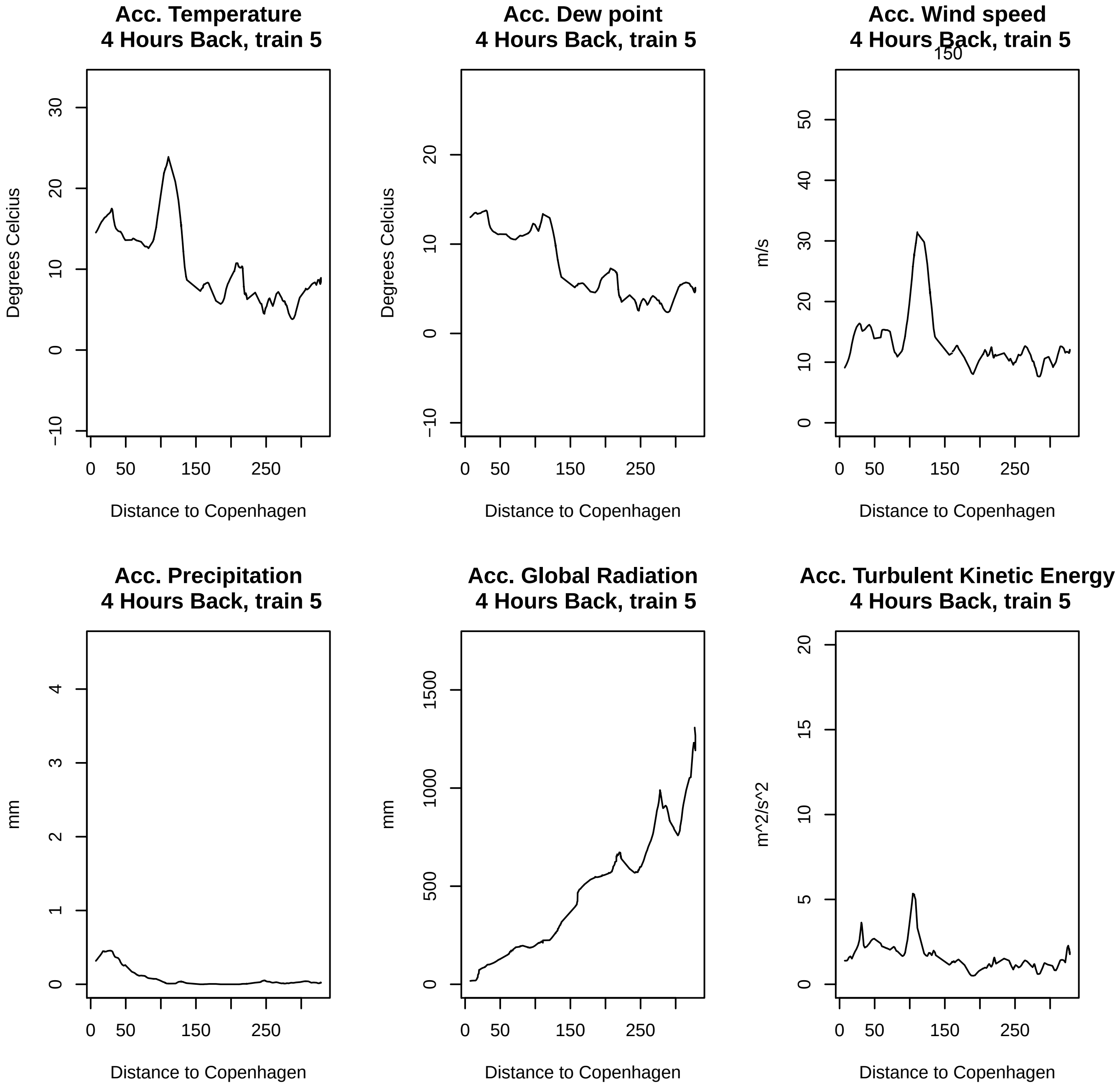
5
10
15
0
50
150
250
Distance to Copenhagen



Acc. Temperature
4 Hours Back, train 5
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 5
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 5
150
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 5
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 5
mm
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500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 5
m^2/s^2
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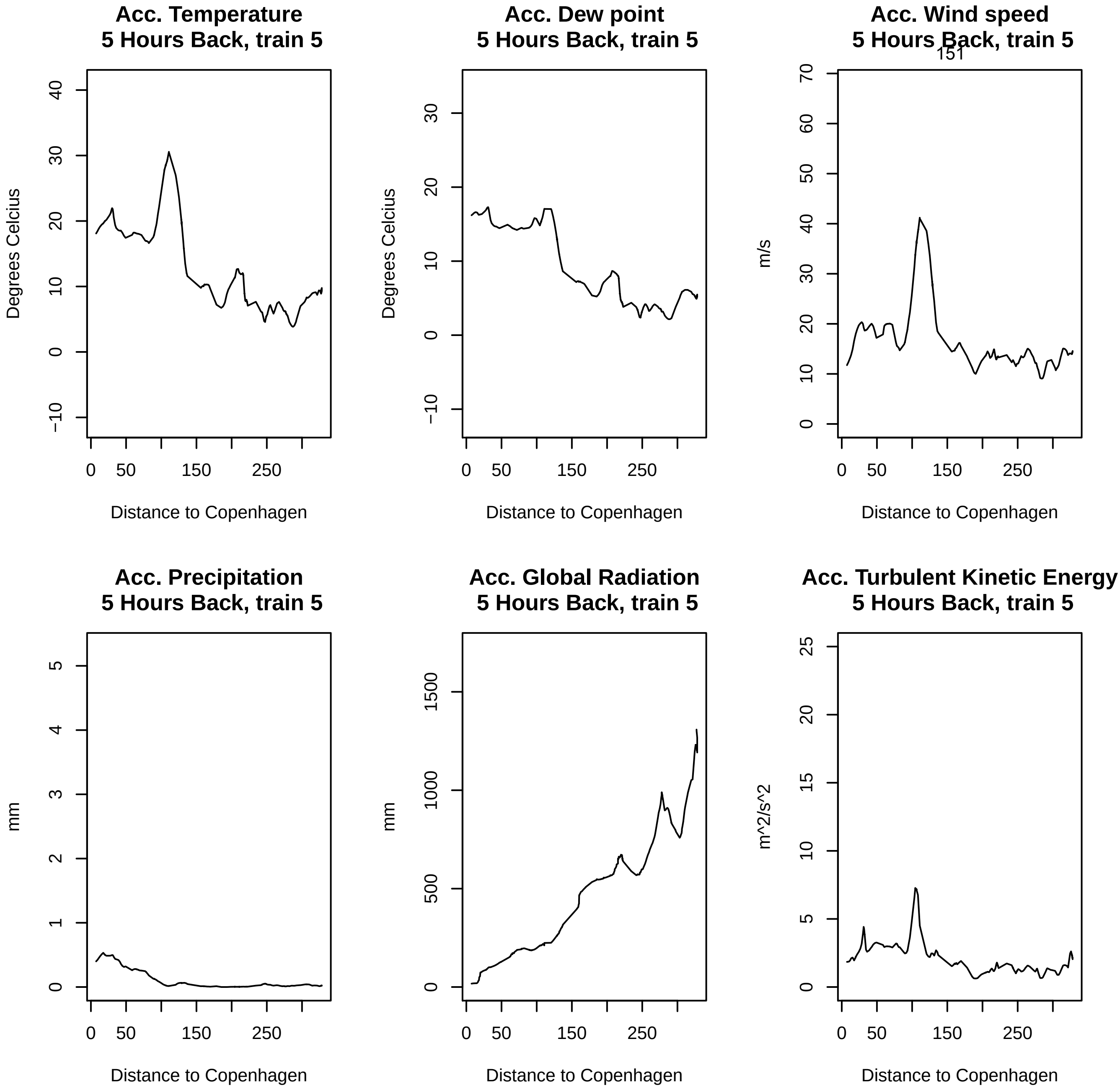
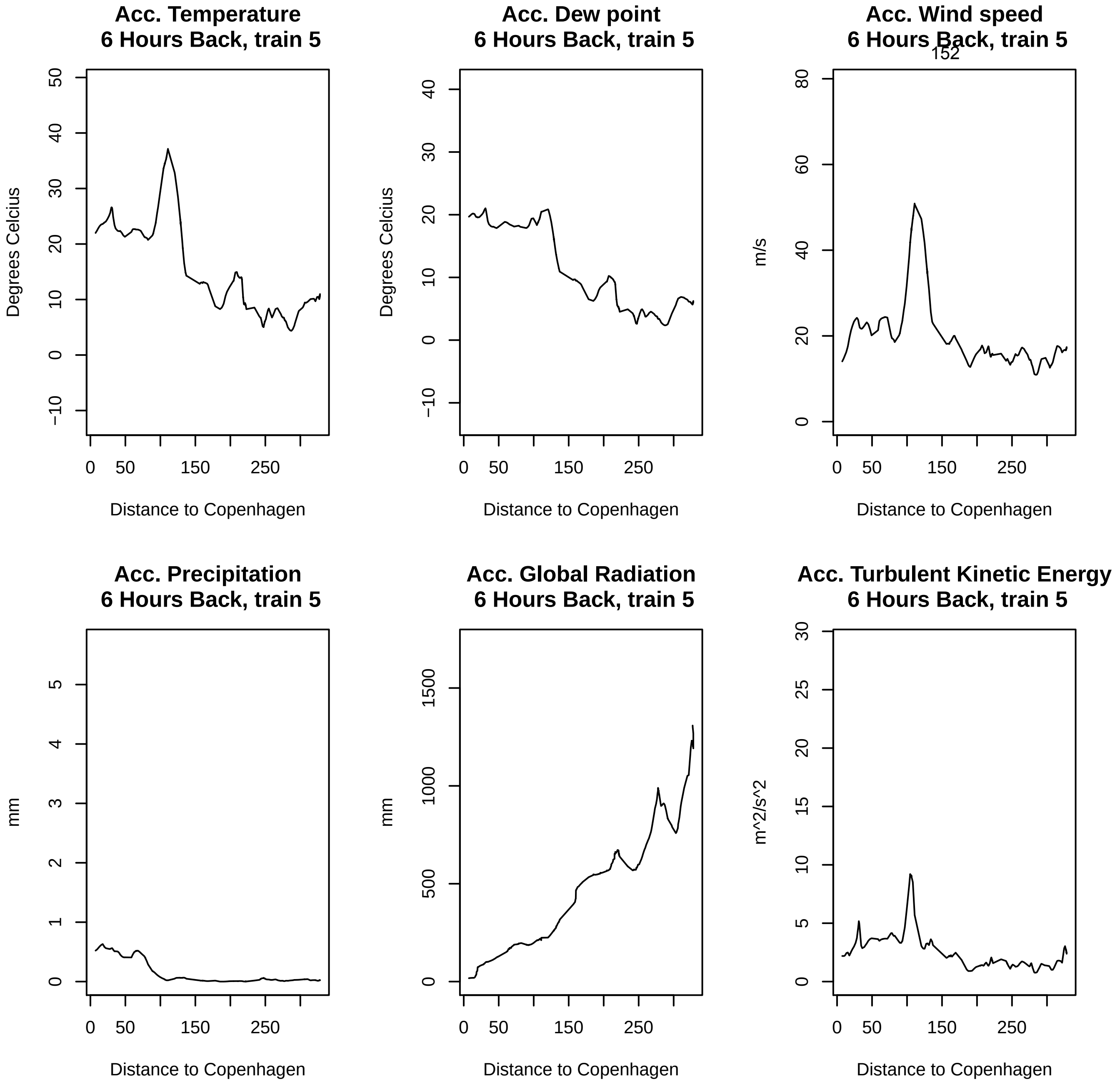
50
150
250
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 5
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 5
m^2/s^2
Distance to Copenhagen



Acc. Temperature
6 Hours Back, train 5
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 5
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 5
m/s
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20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 5
mm
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4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 5
mm
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1500
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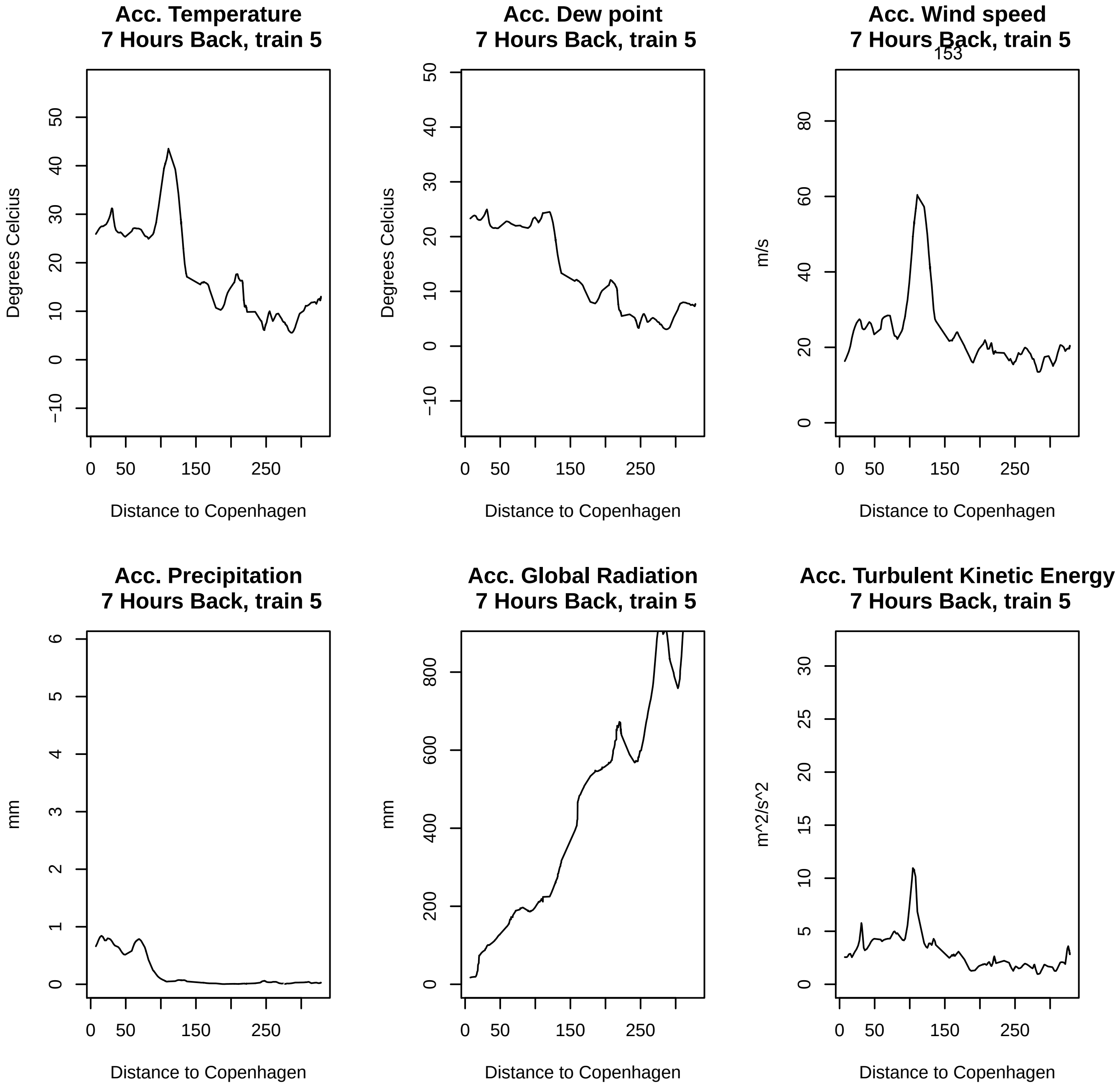
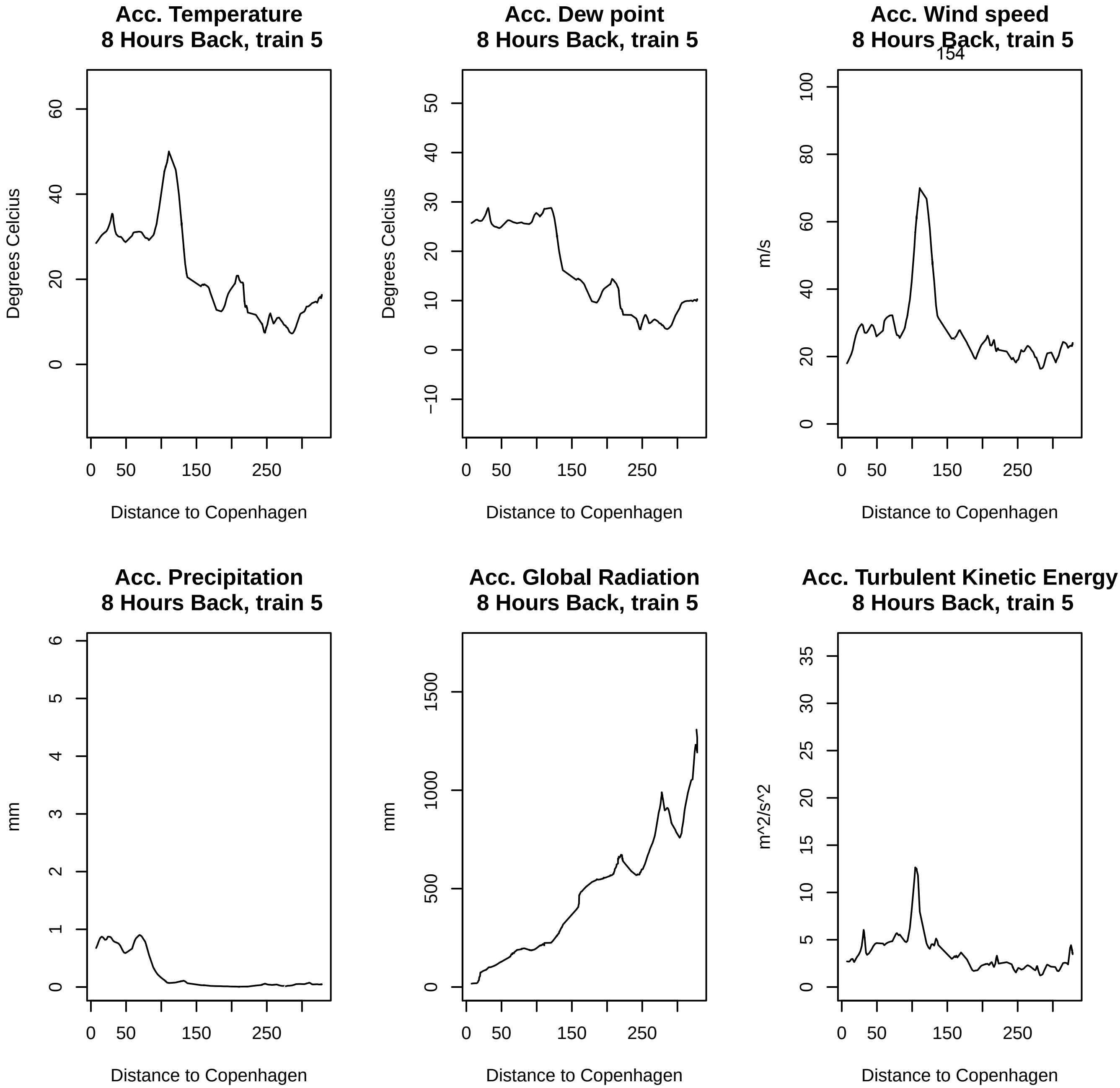
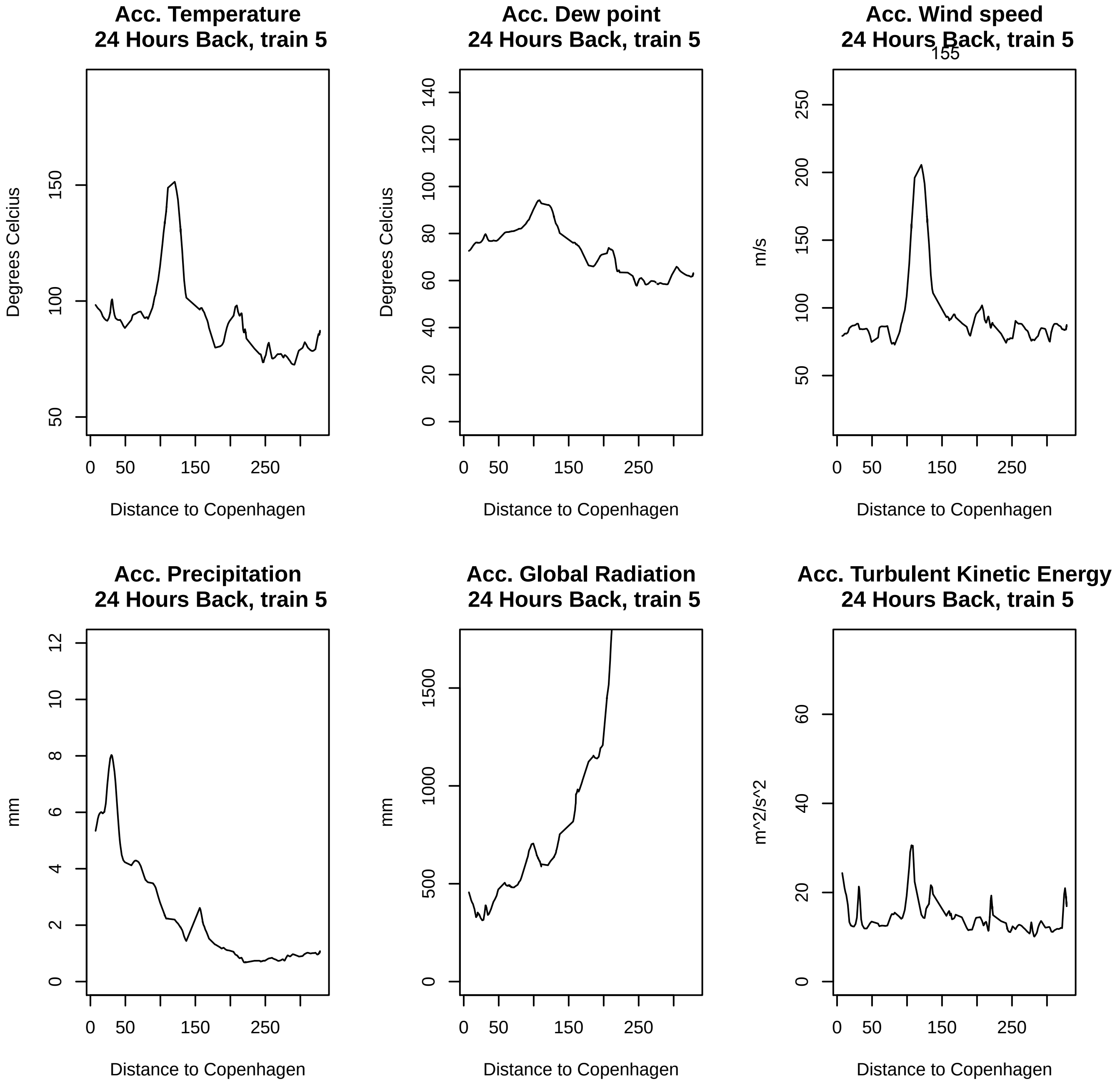
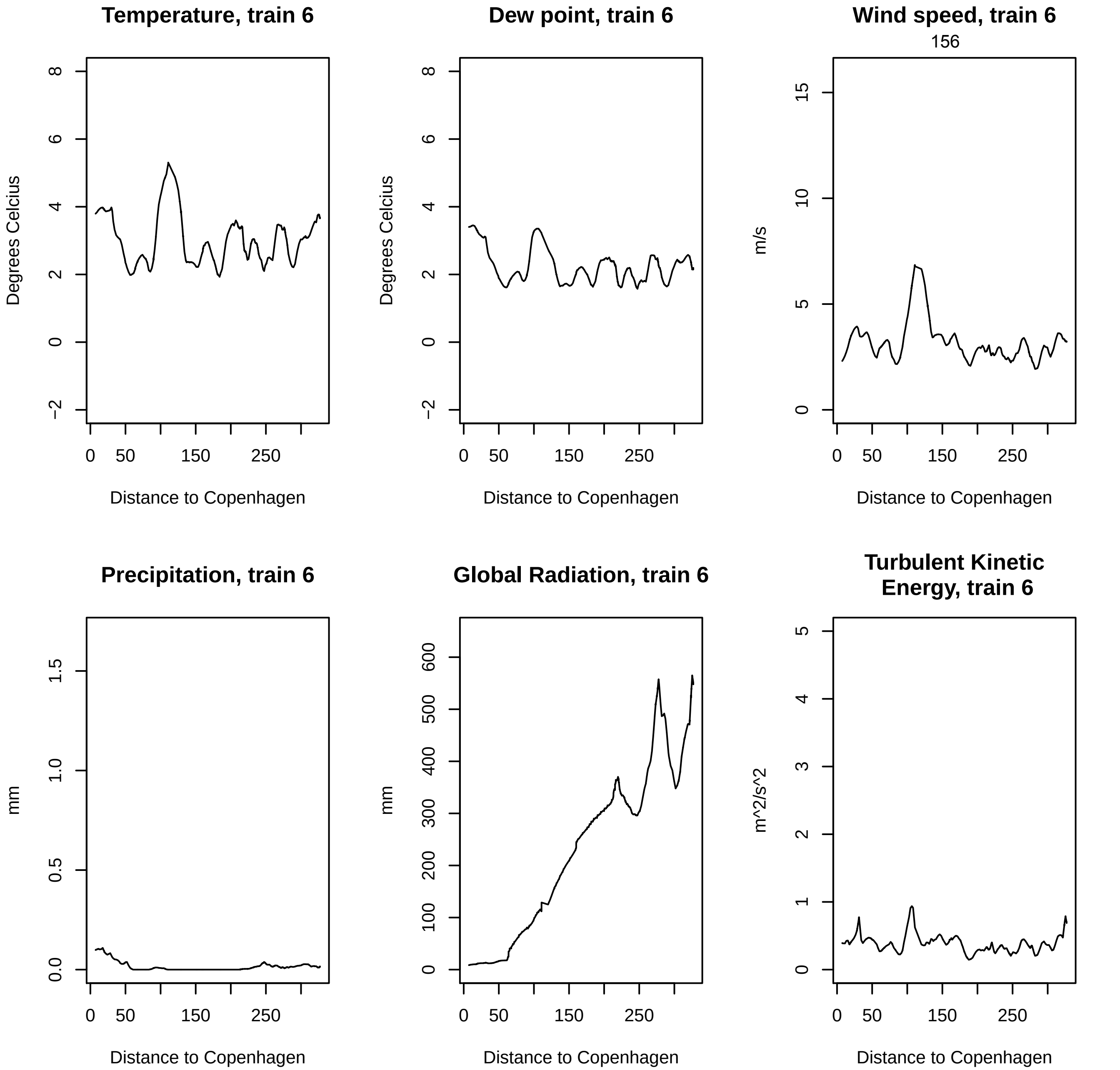
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 5
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

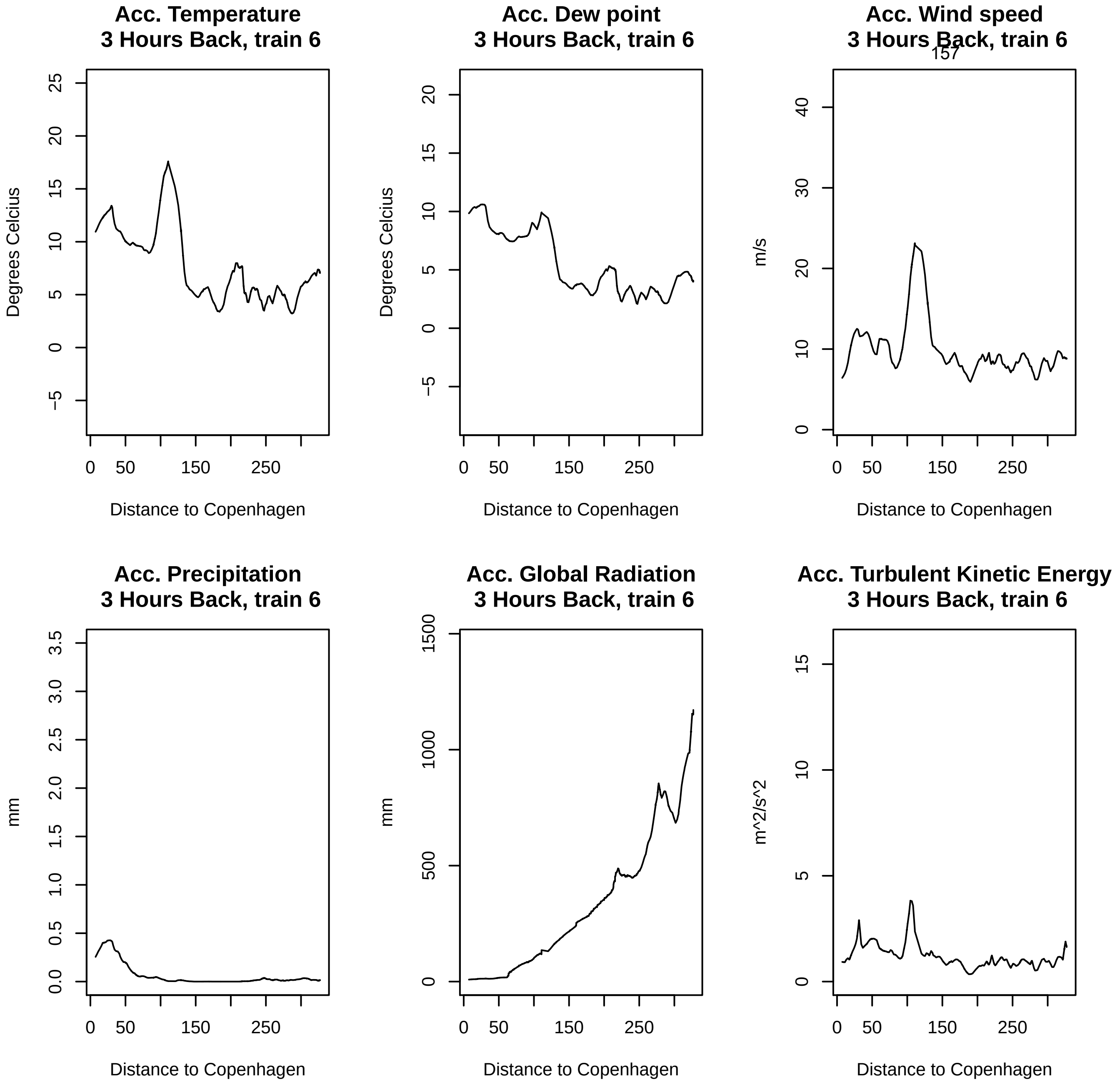

Acc. Temperature
7 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 5
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 5
m^2/s^2
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 5
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 5
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 5
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 5
m^2/s^2
Distance to Copenhagen

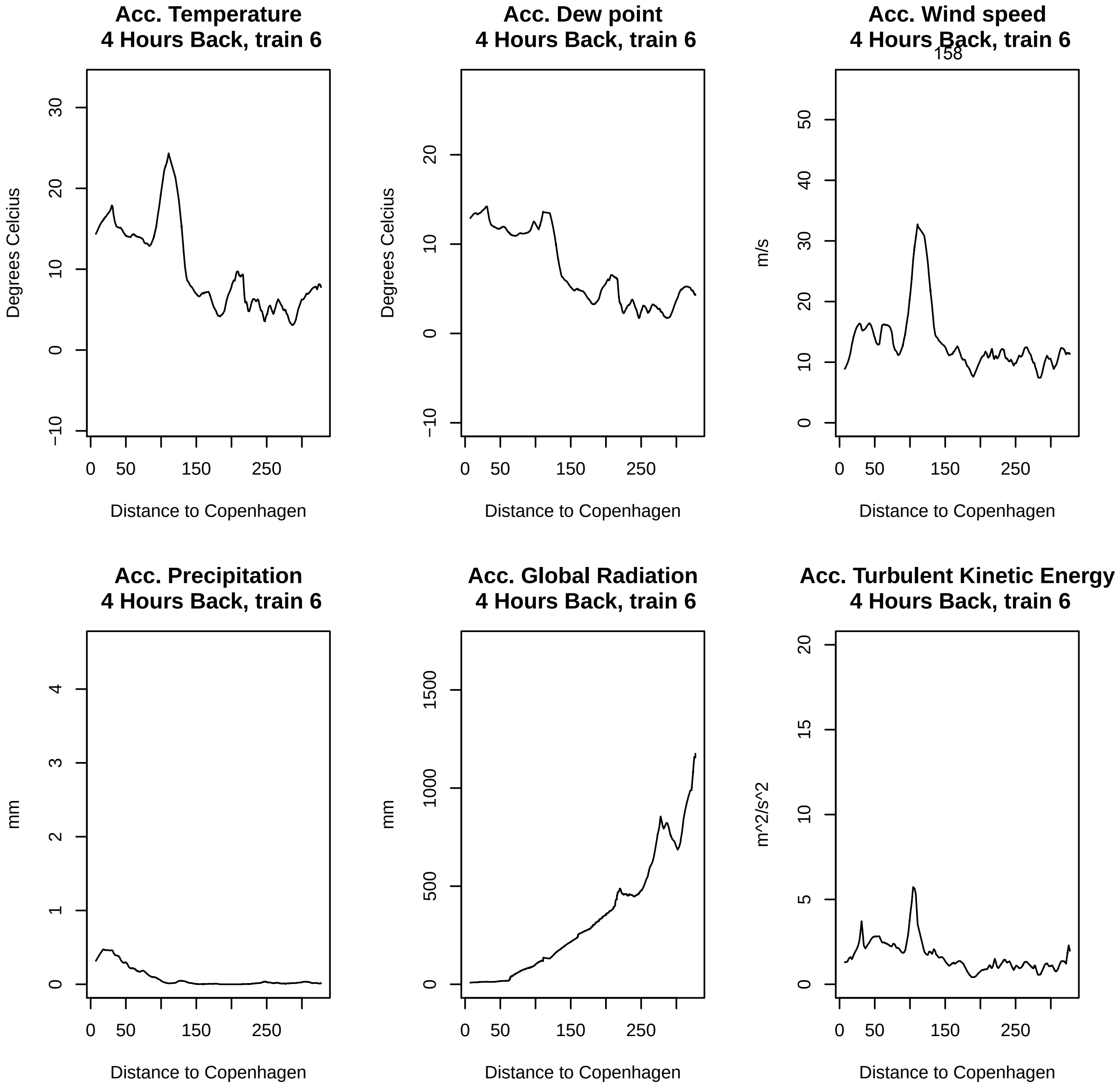

Acc. Temperature
24 Hours Back, train 5
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 5
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 5
155
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 5
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 5
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 5
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

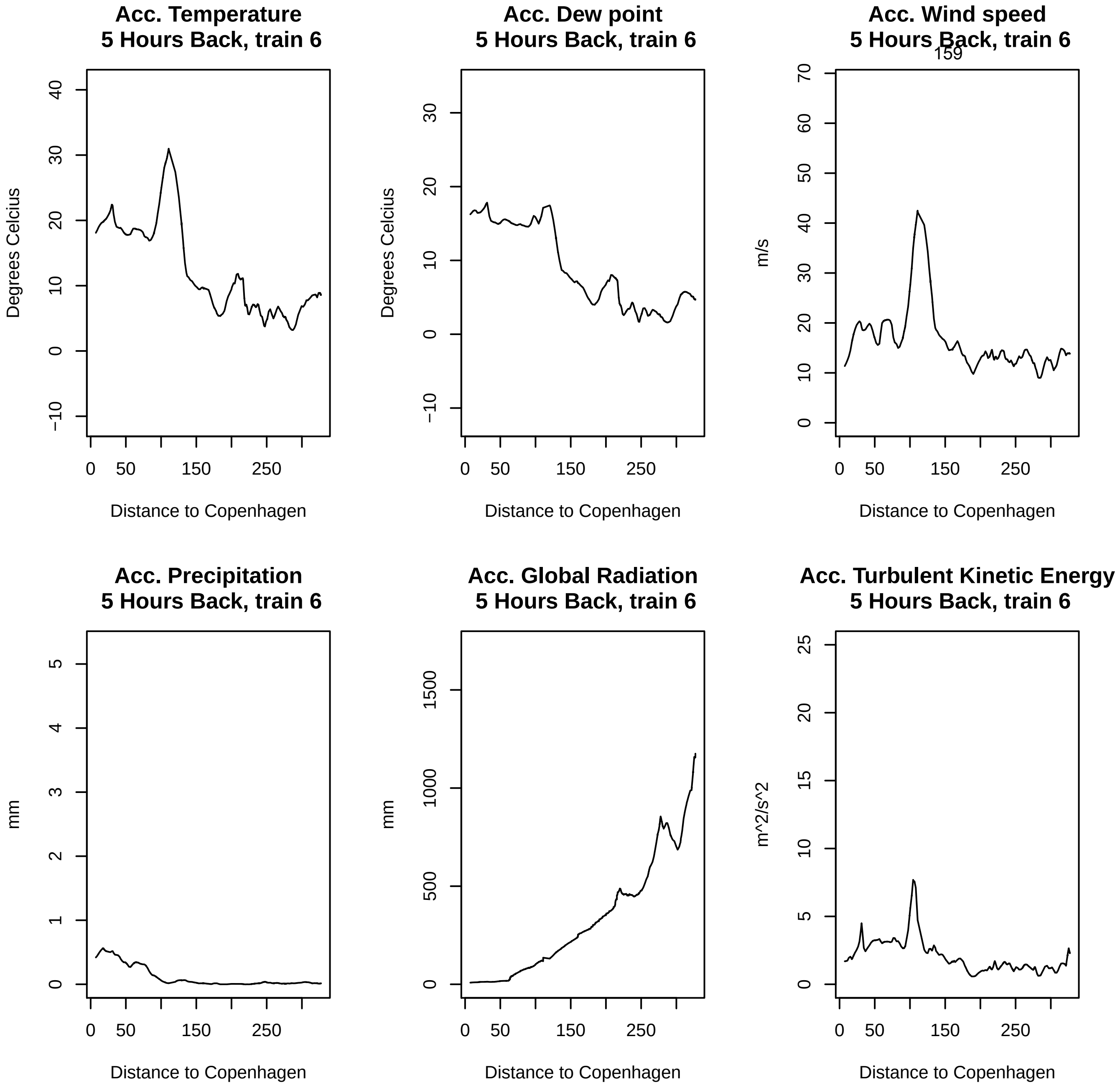


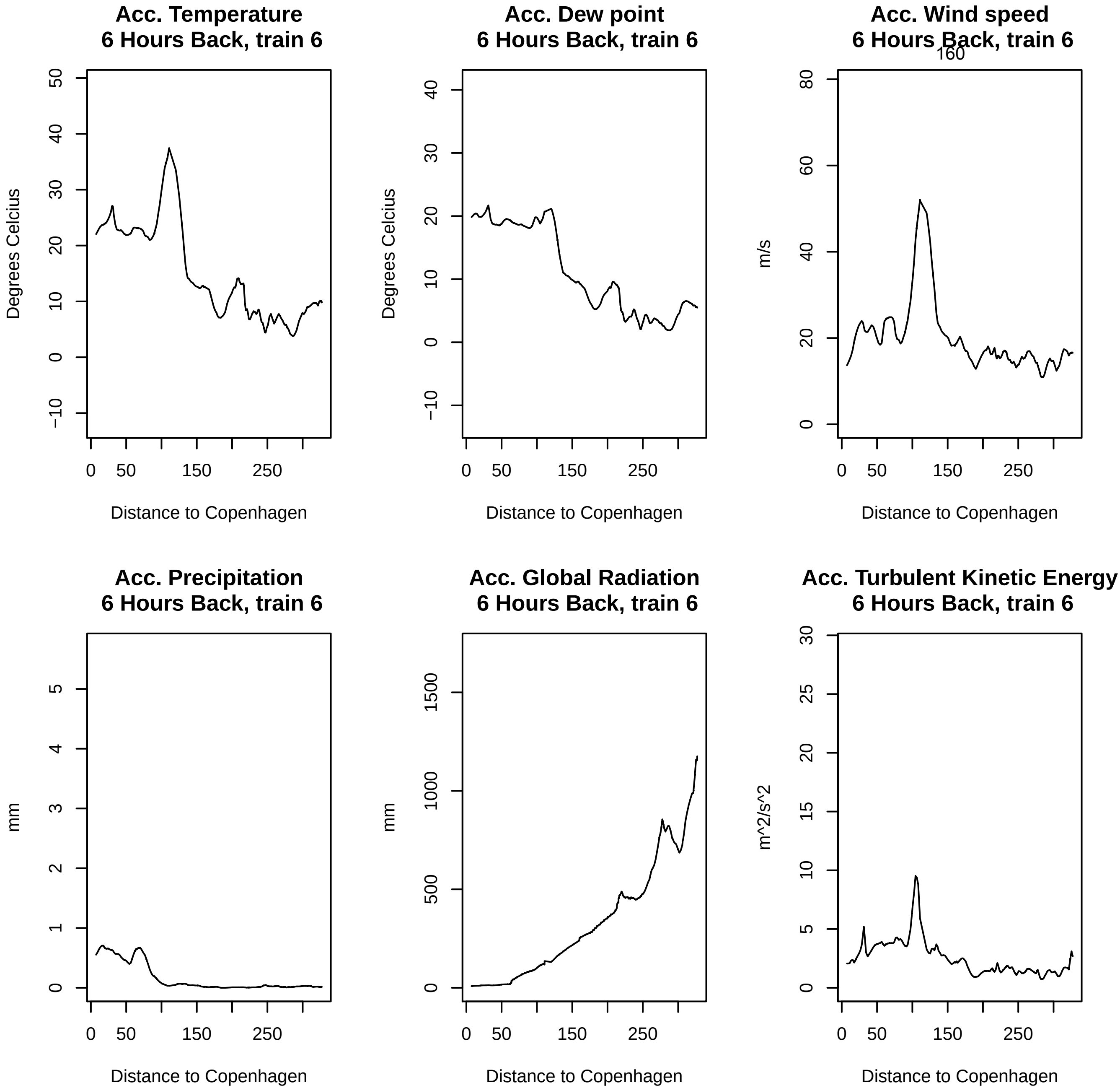
Temperature, train 6
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 6
Degrees Celcius
Wind speed, train 6
m/s
0
5
10
15
Precipitation, train 6
mm
0.0
0.5
1.0
1.5
Global Radiation, train 6
mm
0
100
200
300
400
500
600
Turbulent Kinetic Energy, train 6
m^2/s^2
0
1
2
3
4
5

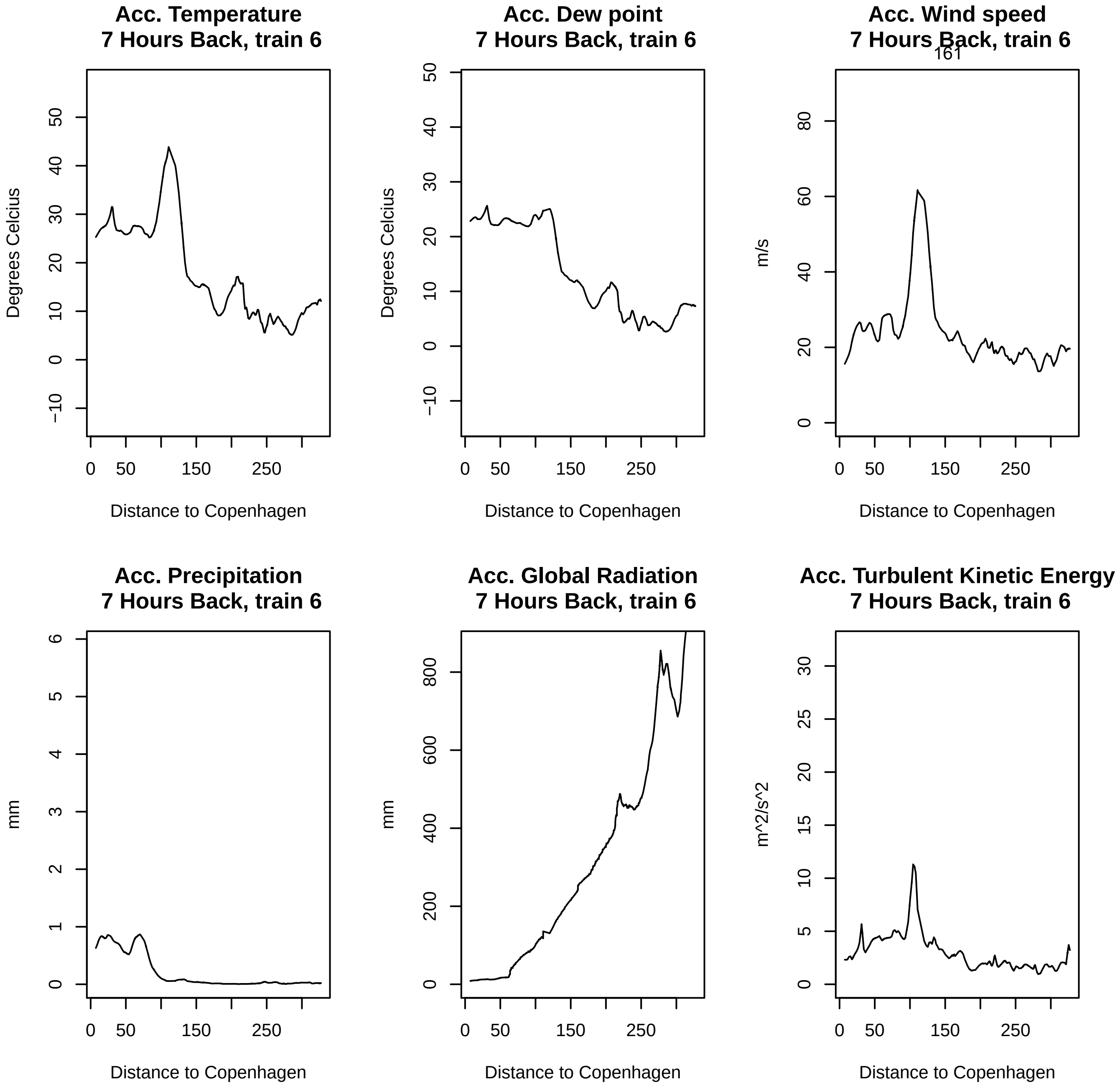


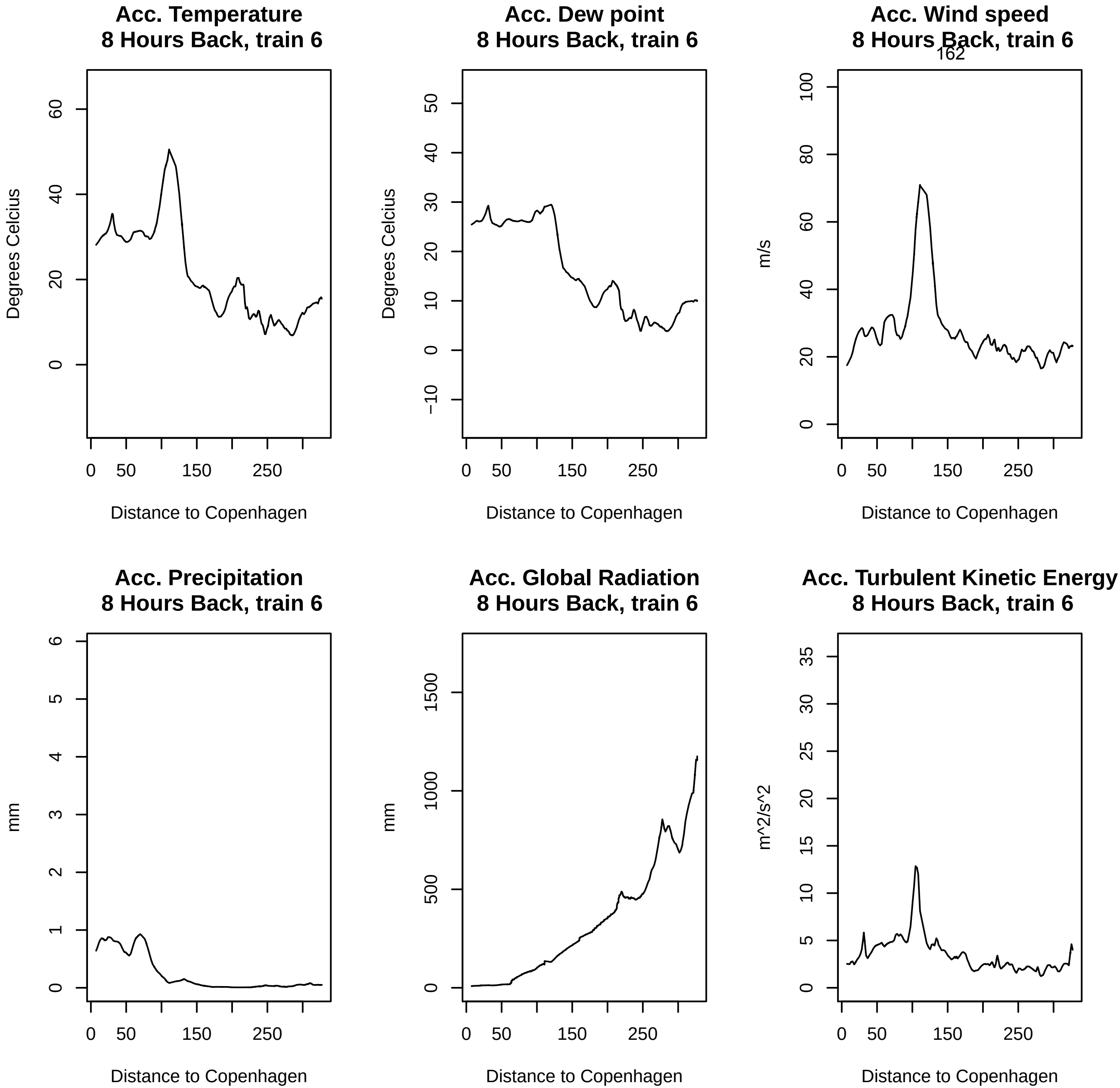
Acc. Temperature
3 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 6
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 6
m^2/s^2
Distance to Copenhagen

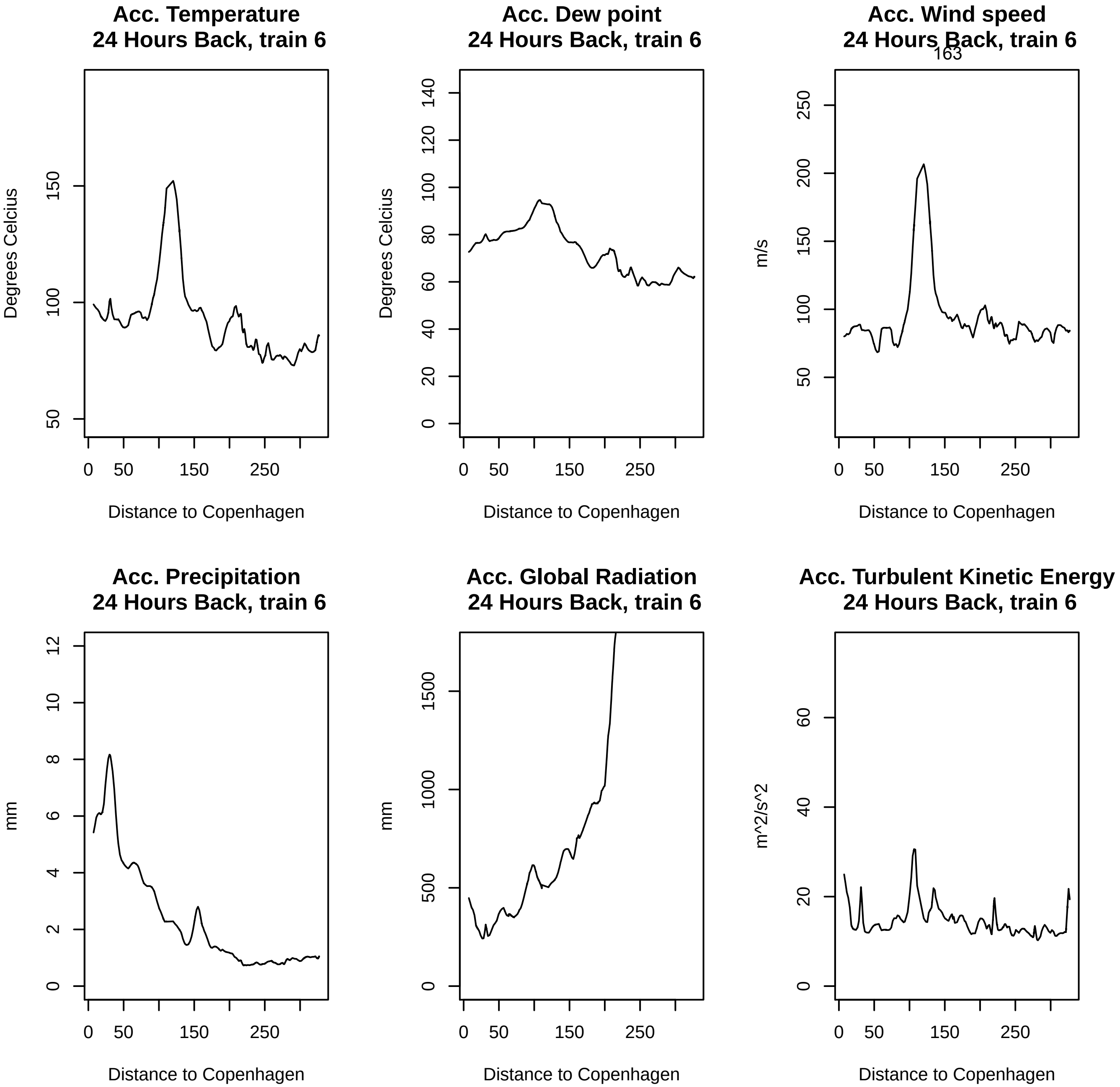

Acc. Temperature
4 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 6
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 6
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 6
Degrees Celcius
−10
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Dew point
5 Hours Back, train 6
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
5 Hours Back, train 6
m/s
0
10
20
30
40
50
60
70
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
5 Hours Back, train 6
mm
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
5 Hours Back, train 6
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
5 Hours Back, train 6
m^2/s^2
0
5
10
15
20
25
Distance to Copenhagen
0
50
150
250

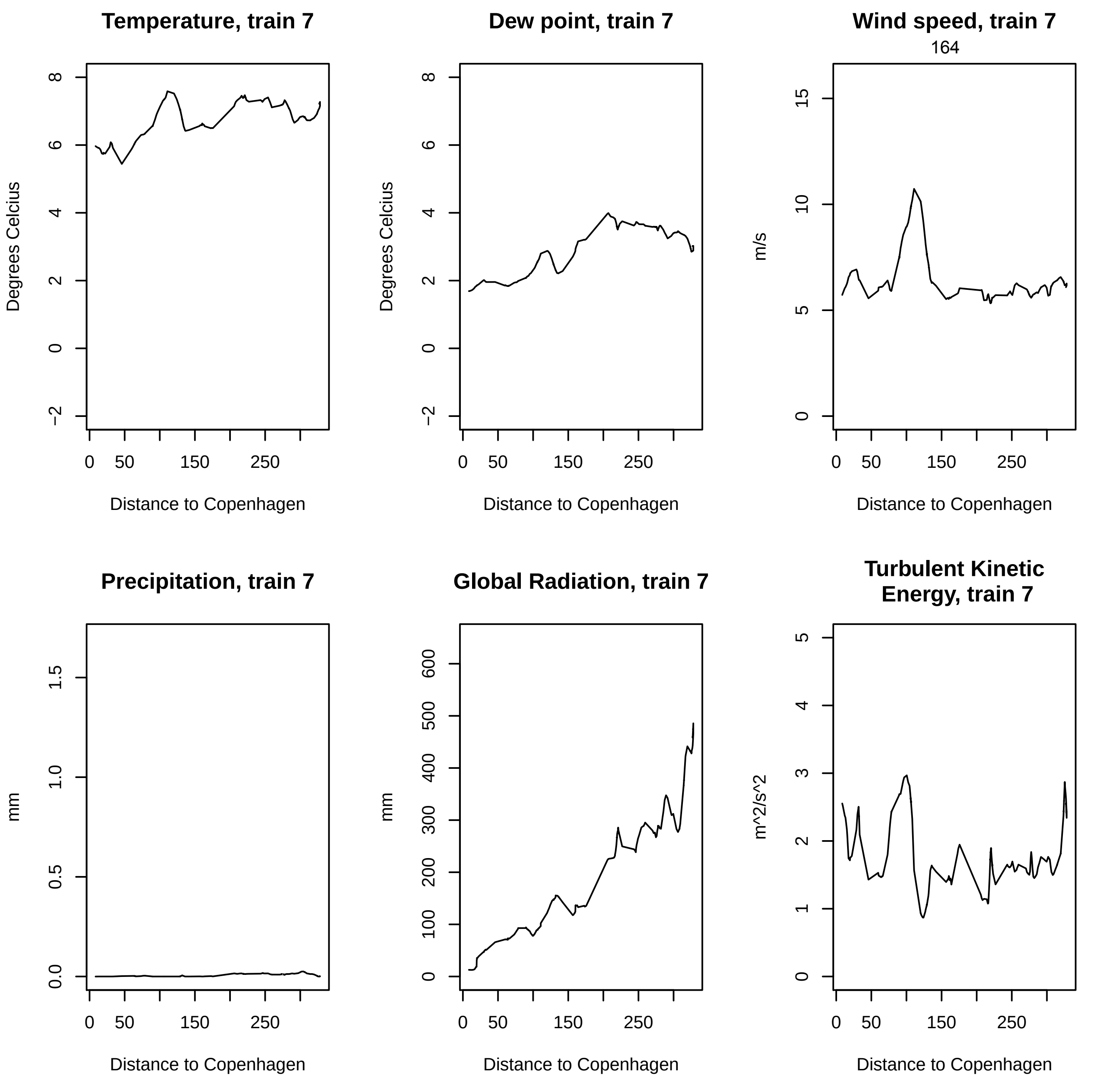

Acc. Temperature
6 Hours Back, train 6
Degrees Celcius
−10
0
10
20
30
40
50
Distance to Copenhagen
0
50
150
250
Acc. Dew point
6 Hours Back, train 6
Degrees Celcius
−10
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
6 Hours Back, train 6
160
m/s
0
20
40
60
80
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
6 Hours Back, train 6
mm
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
6 Hours Back, train 6
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
6 Hours Back, train 6
m^2/s^2
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250


Acc. Temperature
7 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 6
161
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 6
m^2/s^2
Distance to Copenhagen

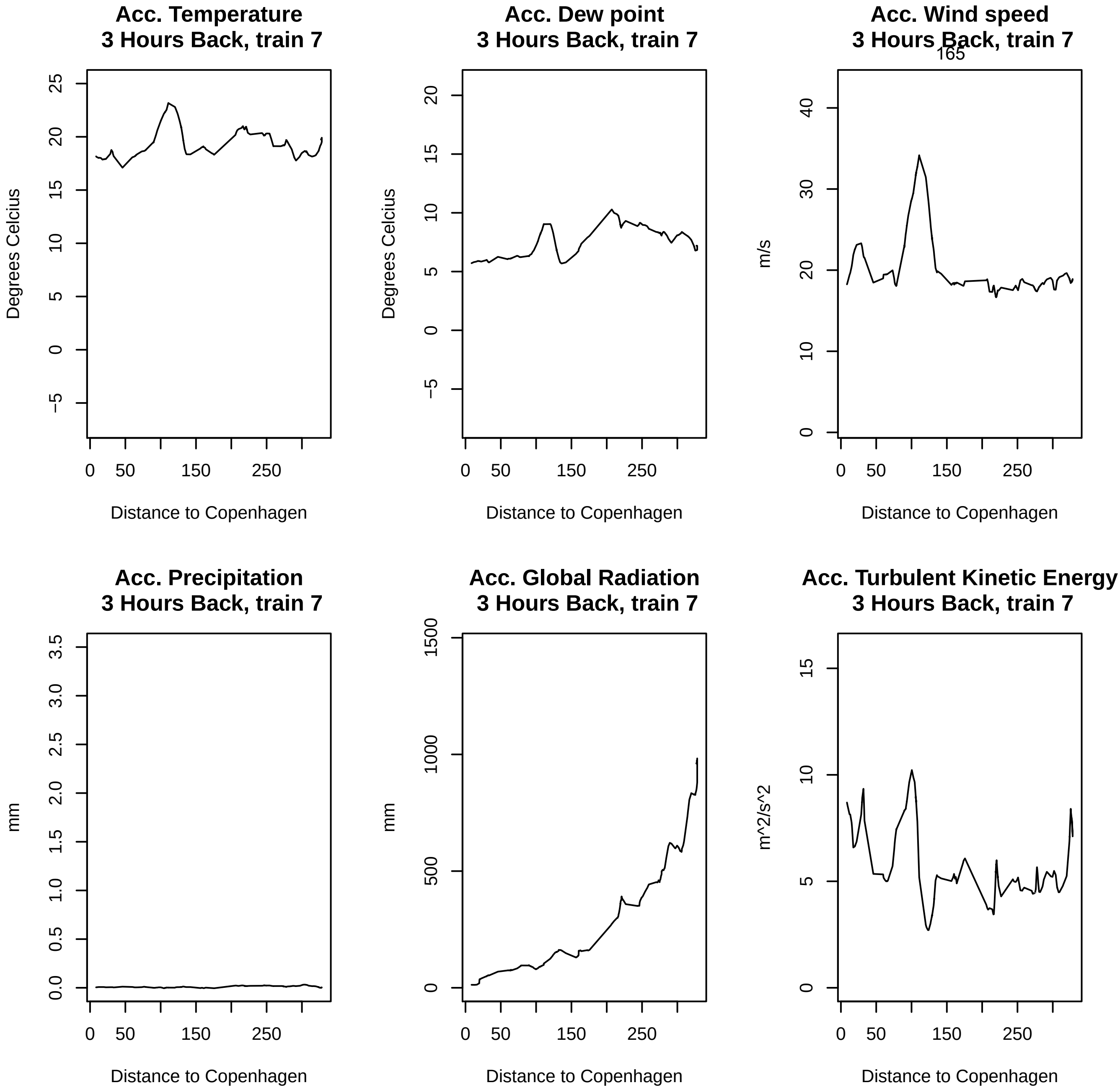

Acc. Temperature
8 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 6
162
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 6
m^2/s^2
Distance to Copenhagen

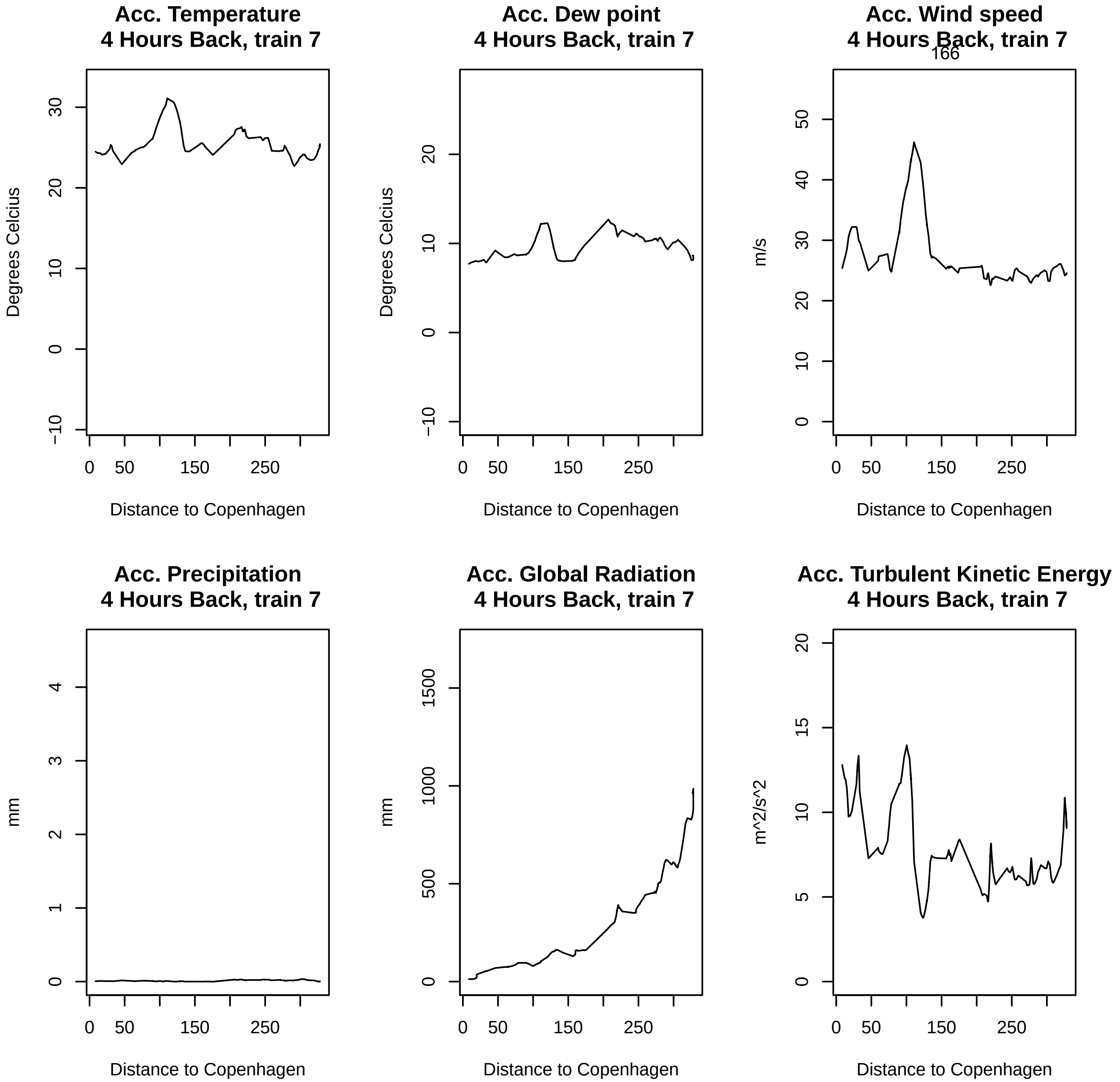


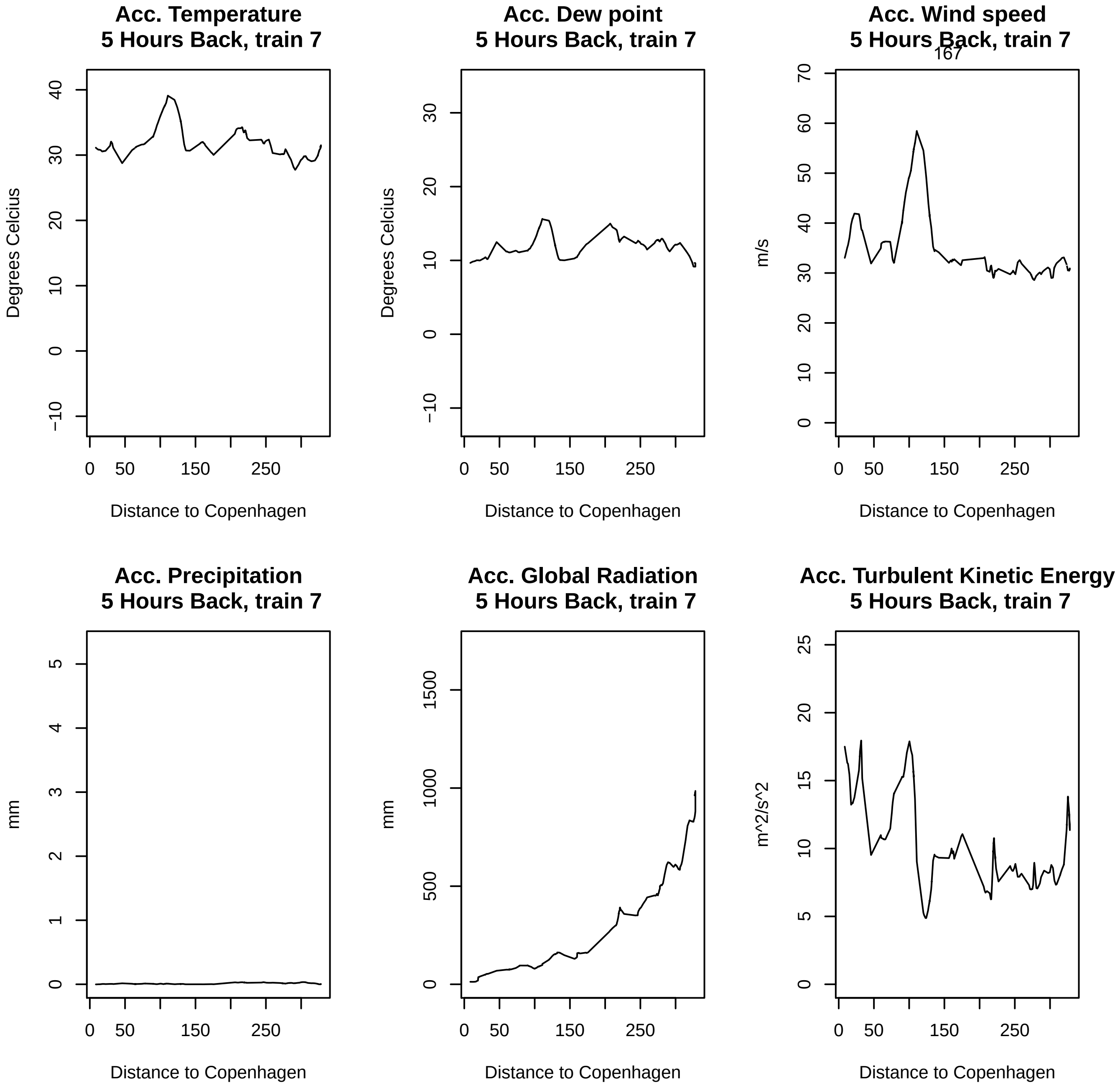
Acc. Temperature
24 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 6
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 6
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 6
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 6
m^2/s^2
Distance to Copenhagen

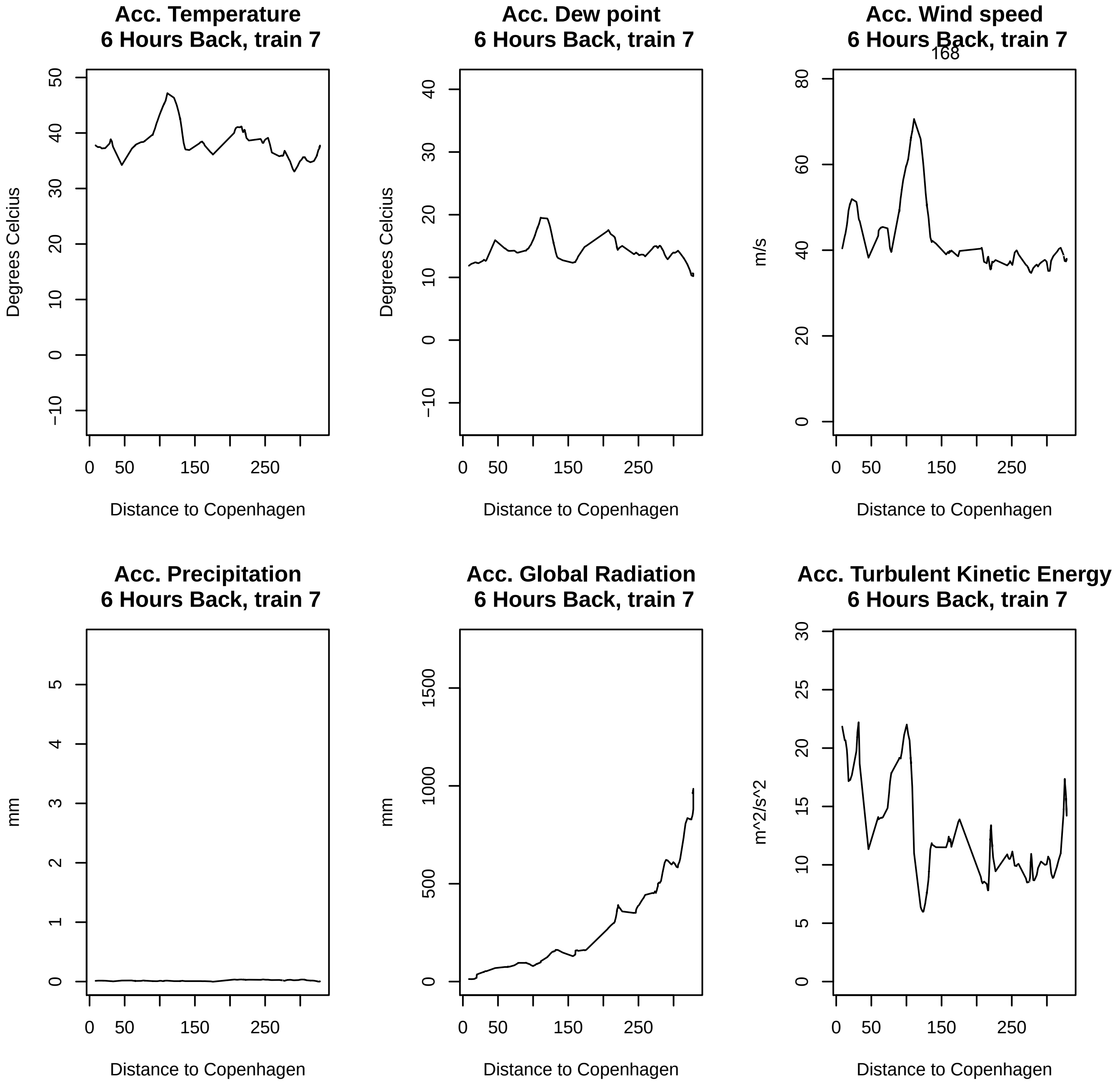


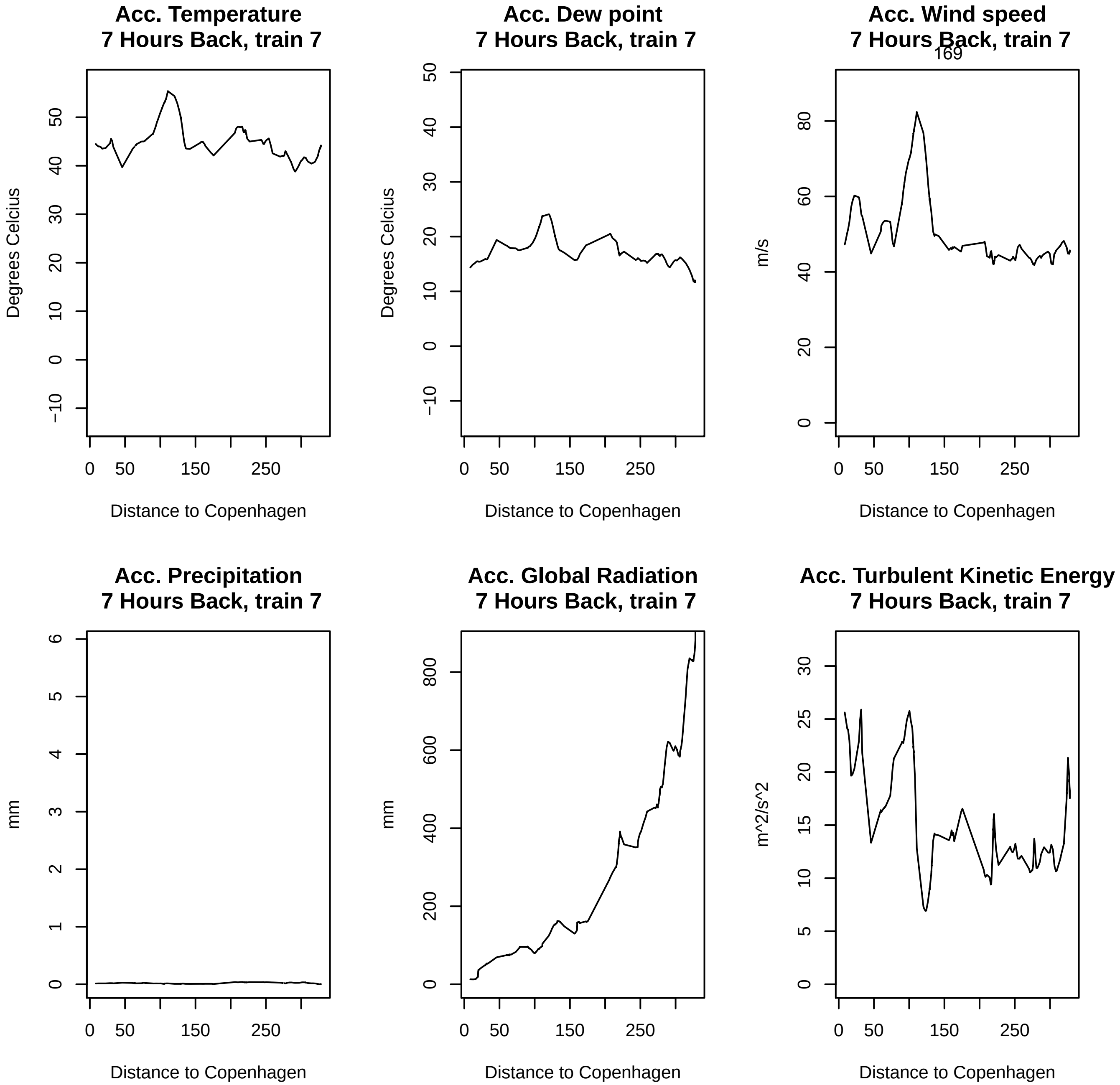
Temperature, train 7
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 7
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Wind speed, train 7
164
m/s
0
5
10
15
0
50
150
250
Distance to Copenhagen
Precipitation, train 7
mm
0.0
0.5
1.0
1.5
0
50
150
250
Distance to Copenhagen
Global Radiation, train 7
mm
0
100
200
300
400
500
600
0
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 7
m^2/s^2
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen

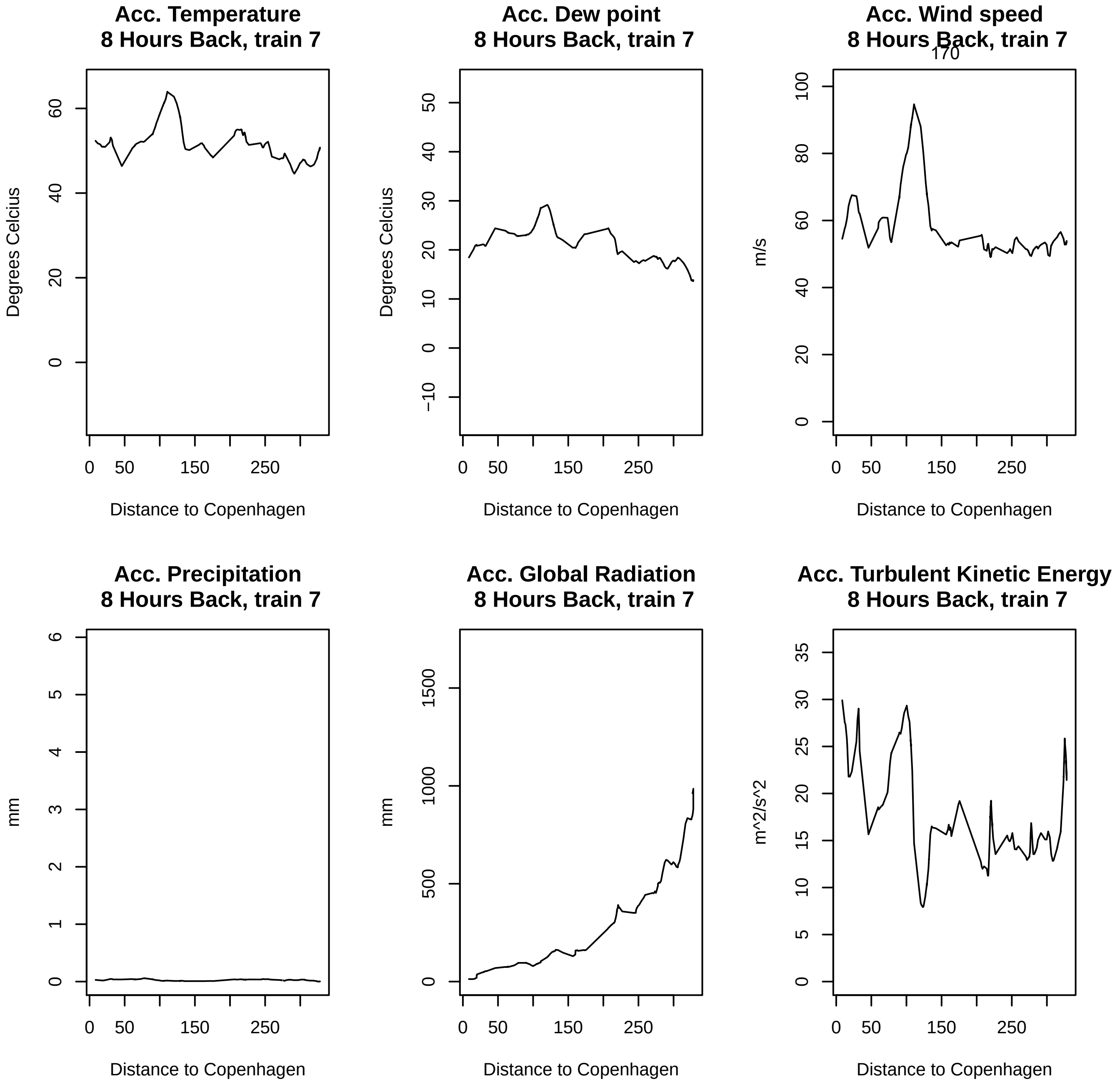

Acc. Temperature
3 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 7
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 7
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 7
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 7
m^2/s^2
Distance to Copenhagen

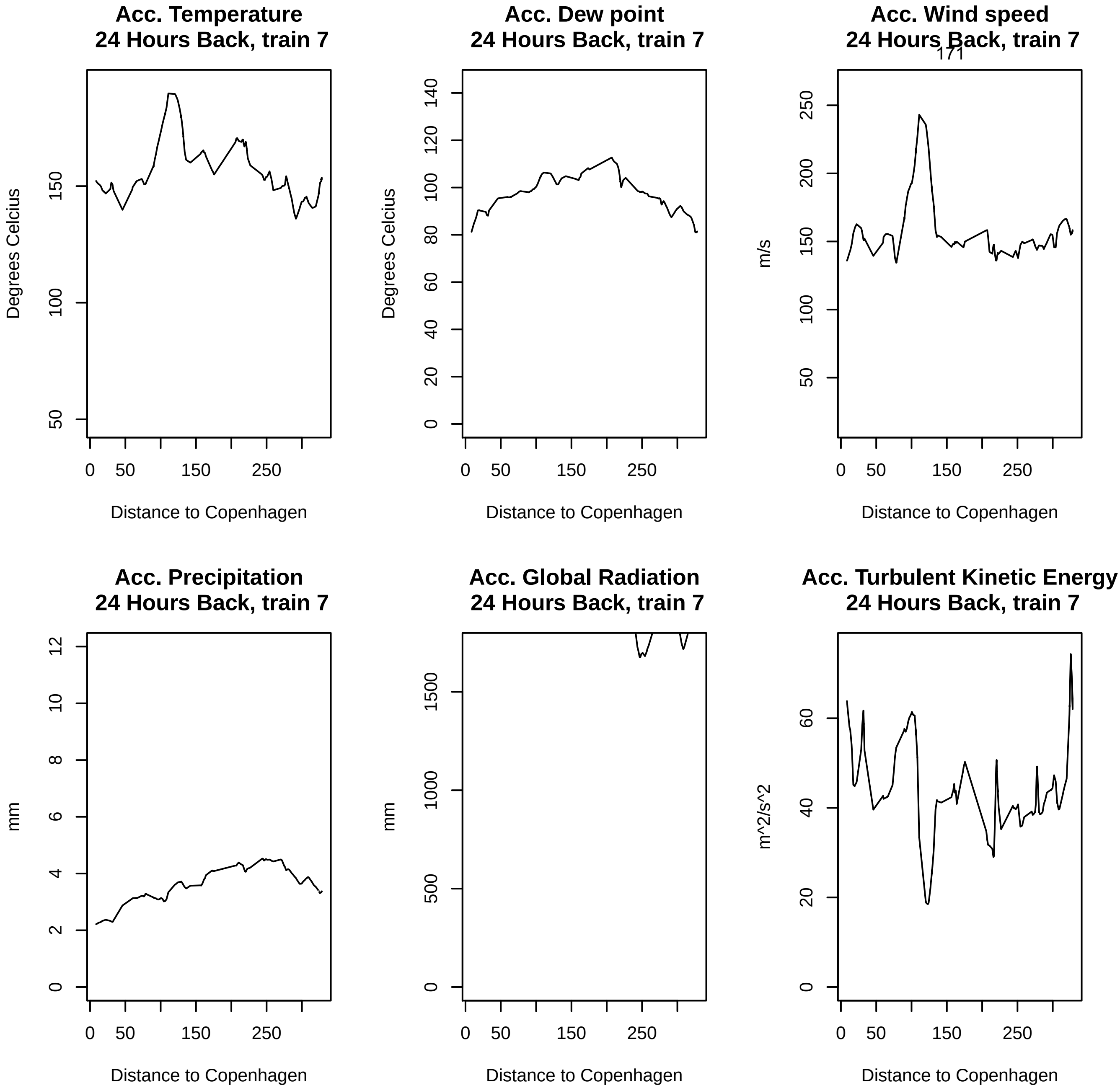

Acc. Temperature
5 Hours Back, train 7
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 7
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 7
m/s
0
10
20
30
40
50
60
70
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 7
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 7
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 7
m^2/s^2
0
5
10
15
20
25
0
50
150
250
Distance to Copenhagen

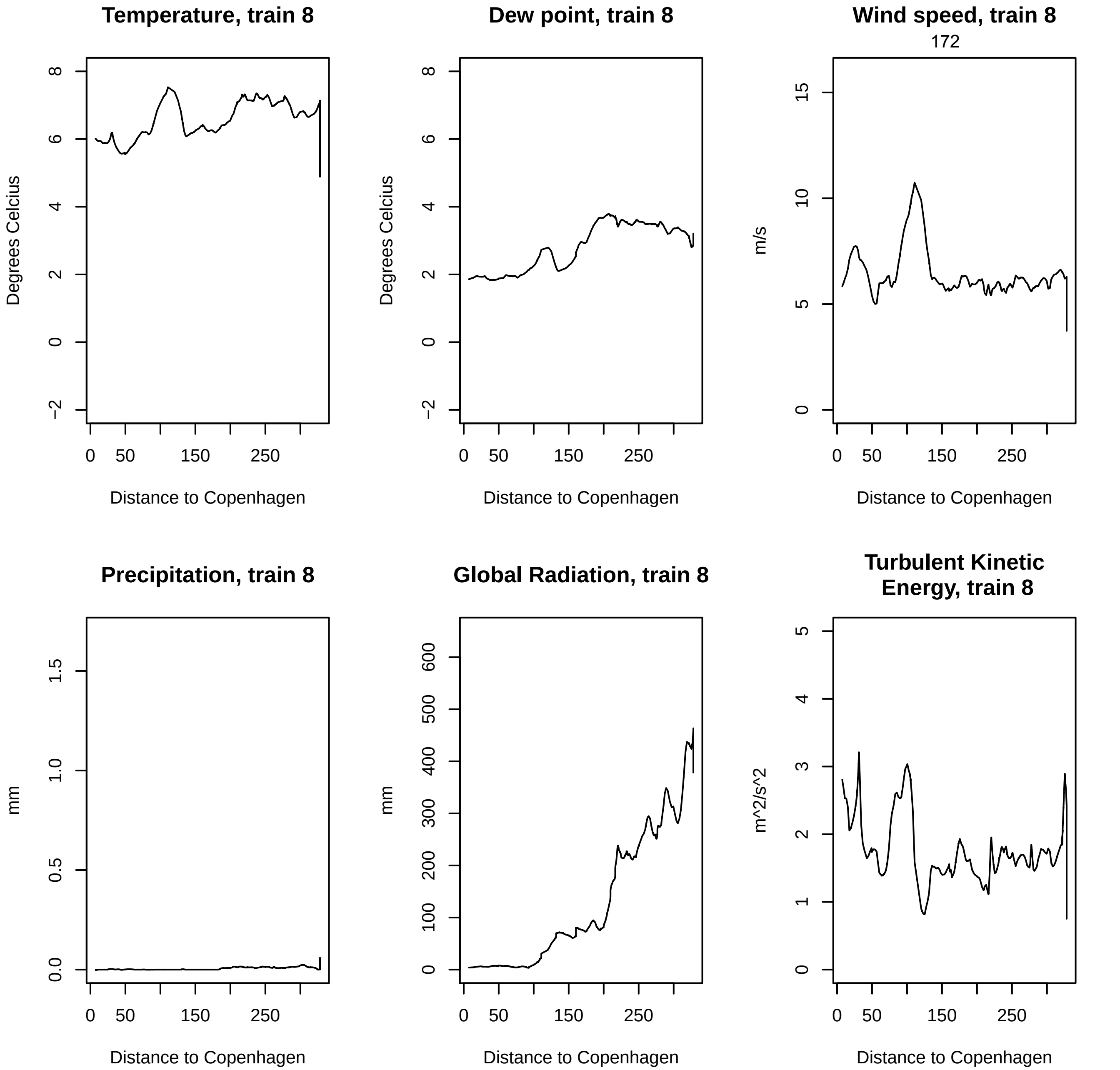

Acc. Temperature
6 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 7
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 7
m^2/s^2
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 7
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 7
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 7
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 7
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 7
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 7
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

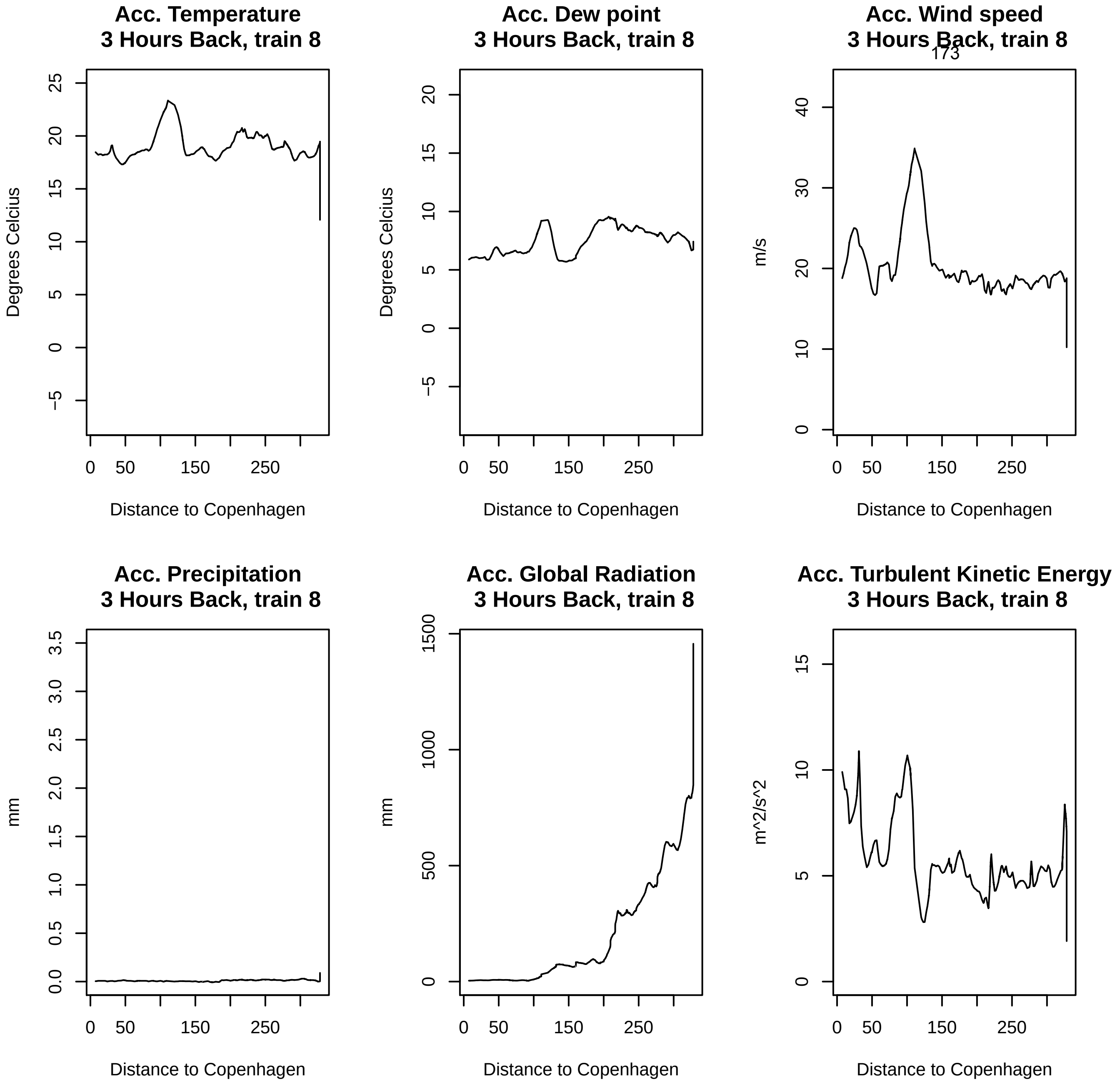


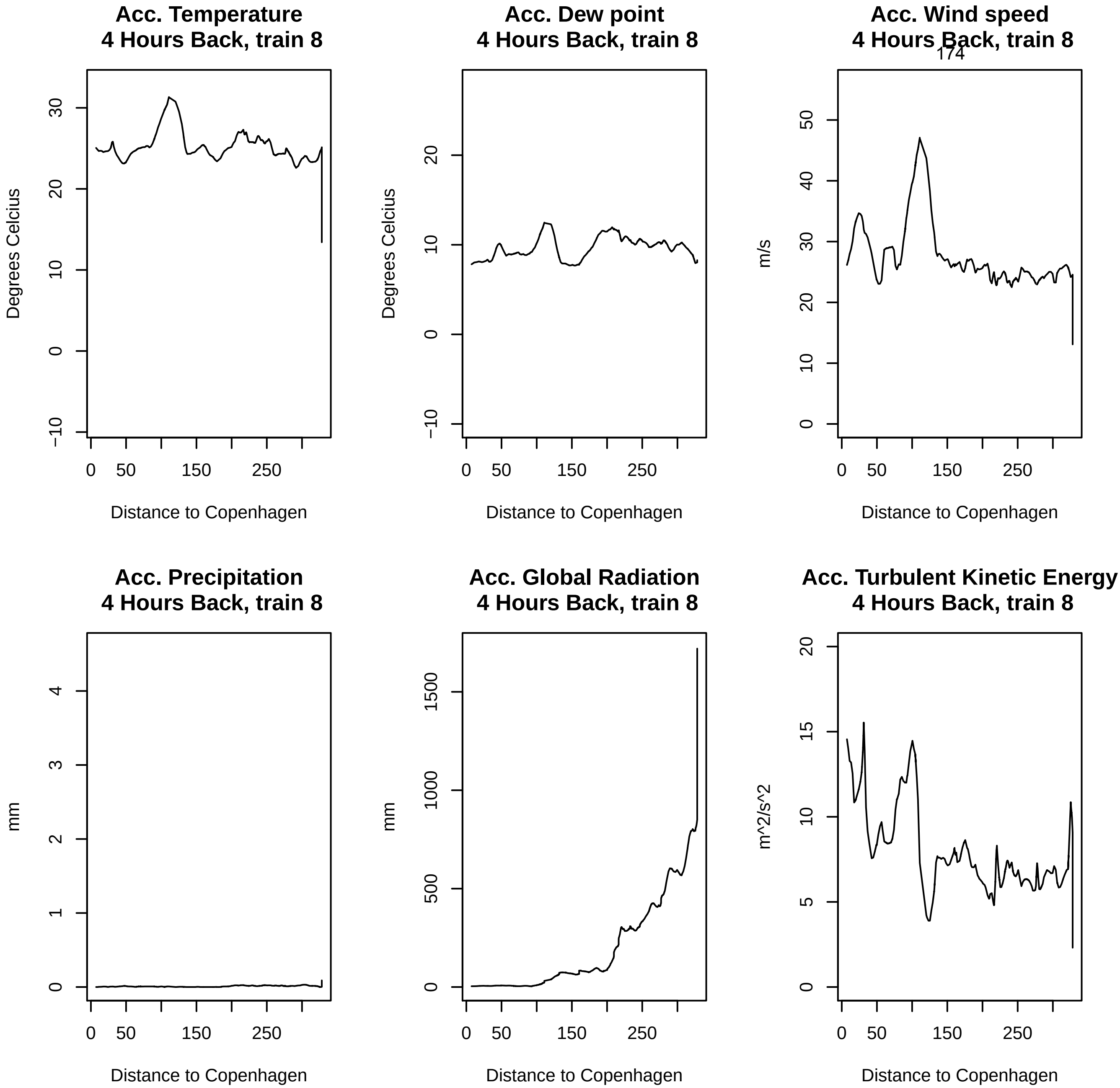
Acc. Temperature
8 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 7
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 7
m^2/s^2
Distance to Copenhagen

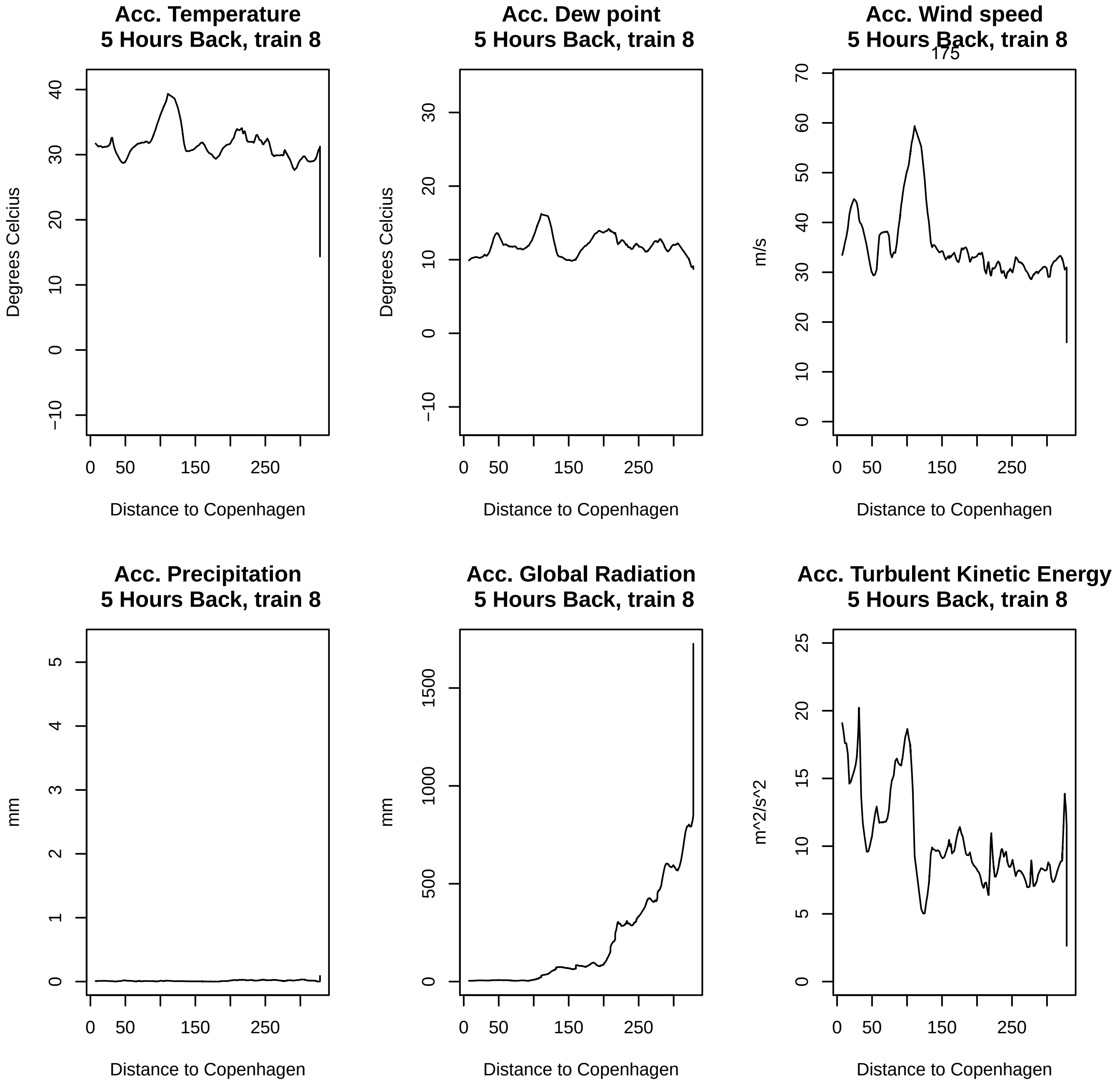

Acc. Temperature
24 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 7
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 7
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 7
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 7
m^2/s^2
Distance to Copenhagen



Temperature, train 8
Degrees Celcius
−2
0
2
4
6
8
Distance to Copenhagen
0
50
150
250
Dew point, train 8
Degrees Celcius
Wind speed, train 8
172
m/s
0
5
10
15
Precipitation, train 8
mm
0.0
0.5
1.0
1.5
Global Radiation, train 8
mm
100
200
300
400
500
600
Turbulent Kinetic Energy, train 8
m^2/s^2
1
2
3
4
5


Acc. Temperature
3 Hours Back, train 8
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 8
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 8
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 8
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 8
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 8
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 8
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 8
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 8
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 8
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 8
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 8
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 8
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 8
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 8
175
m/s
0
10
20
30
40
50
60
70
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 8
mm
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1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 8
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 8
m^2/s^2
0
5
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15
20
25
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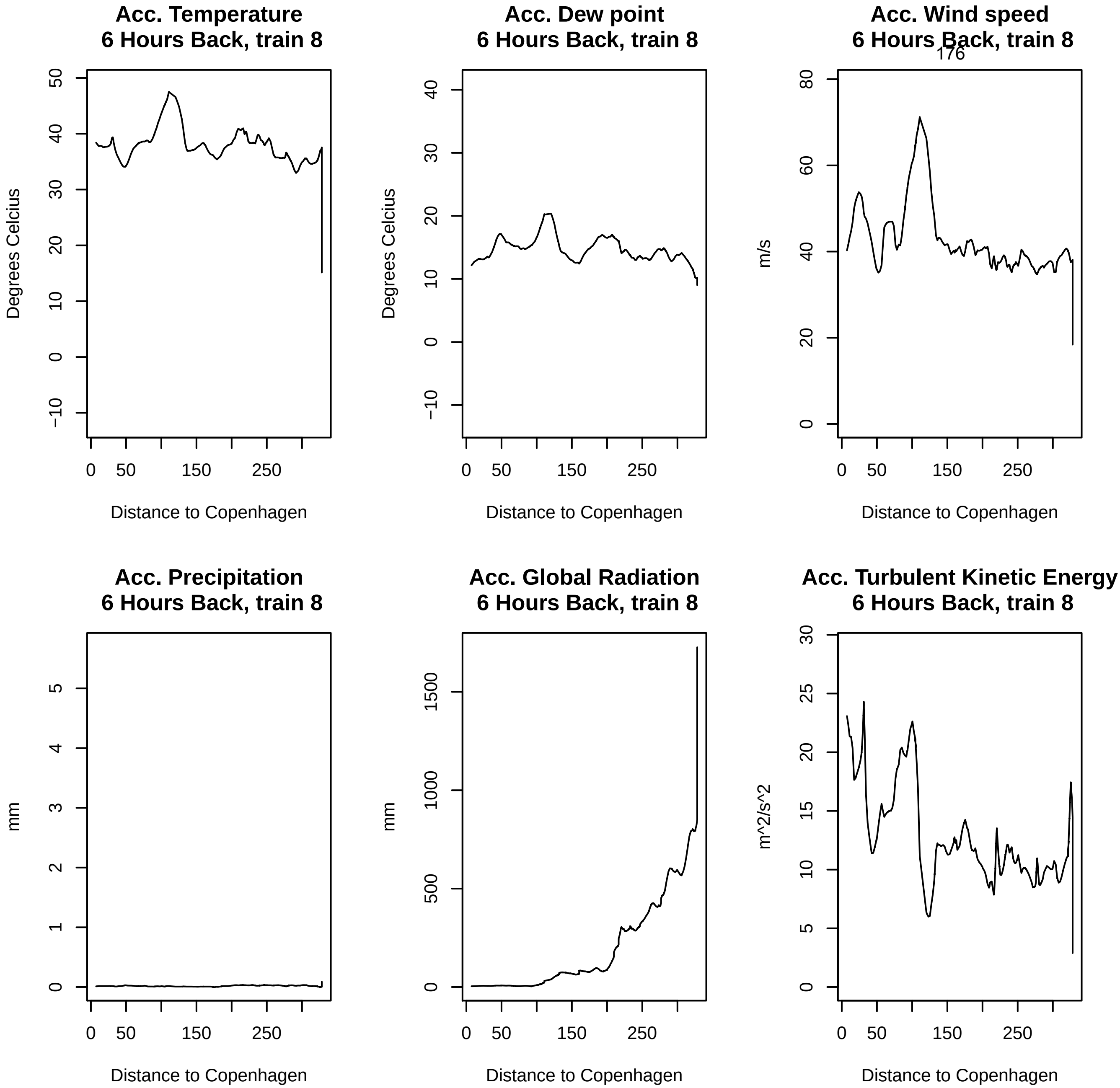
50
150
250
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 8
Degrees Celcius
−10
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10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 8
Degrees Celcius
−10
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20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 8
m/s
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50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 8
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3
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50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 8
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 8
m^2/s^2
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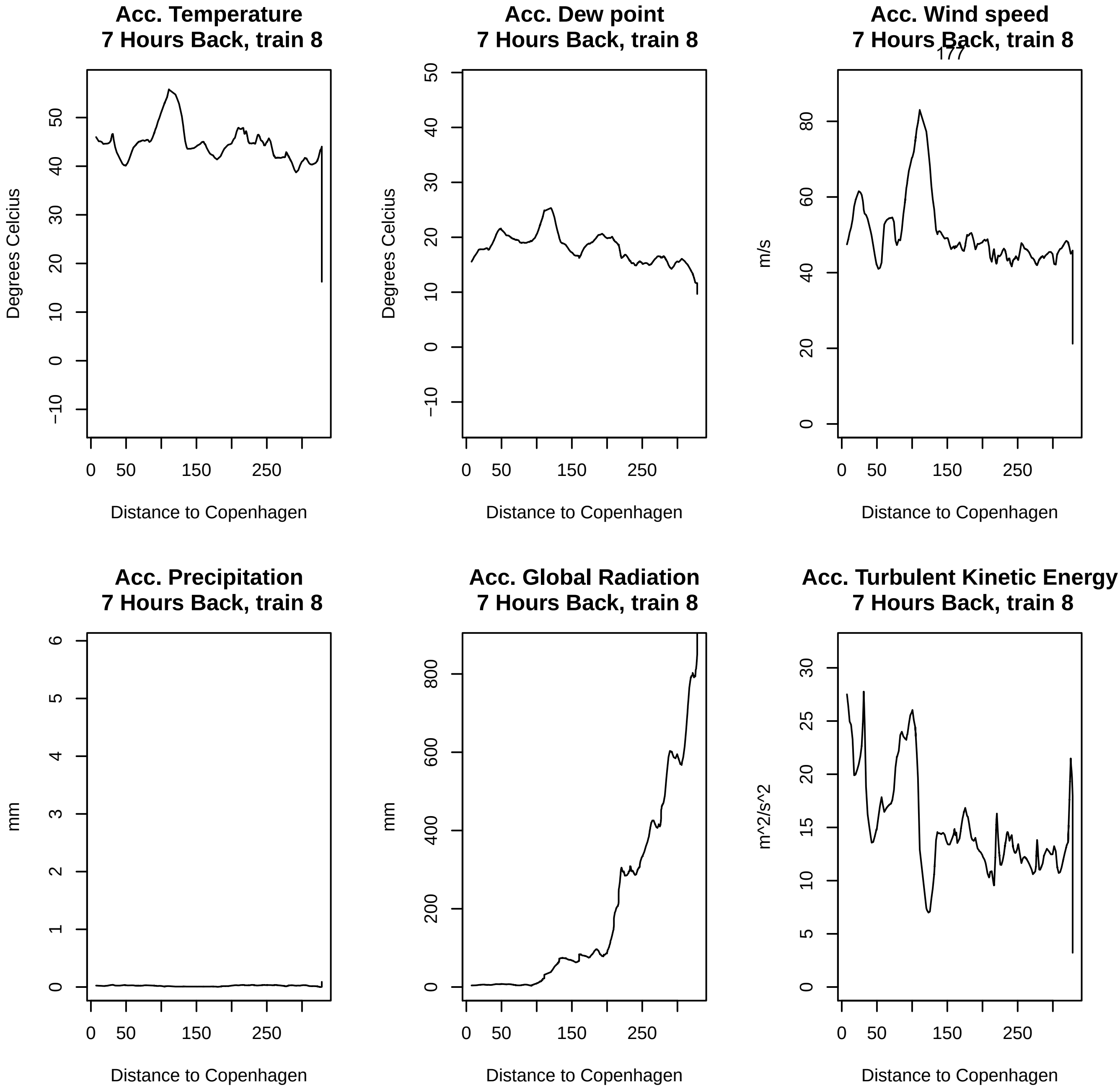
50
150
250
Distance to Copenhagen



Acc. Temperature
7 Hours Back, train 8
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 8
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 8
177
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 8
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 8
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 8
m^2/s^2
0
5
10
15
20
25
30
0
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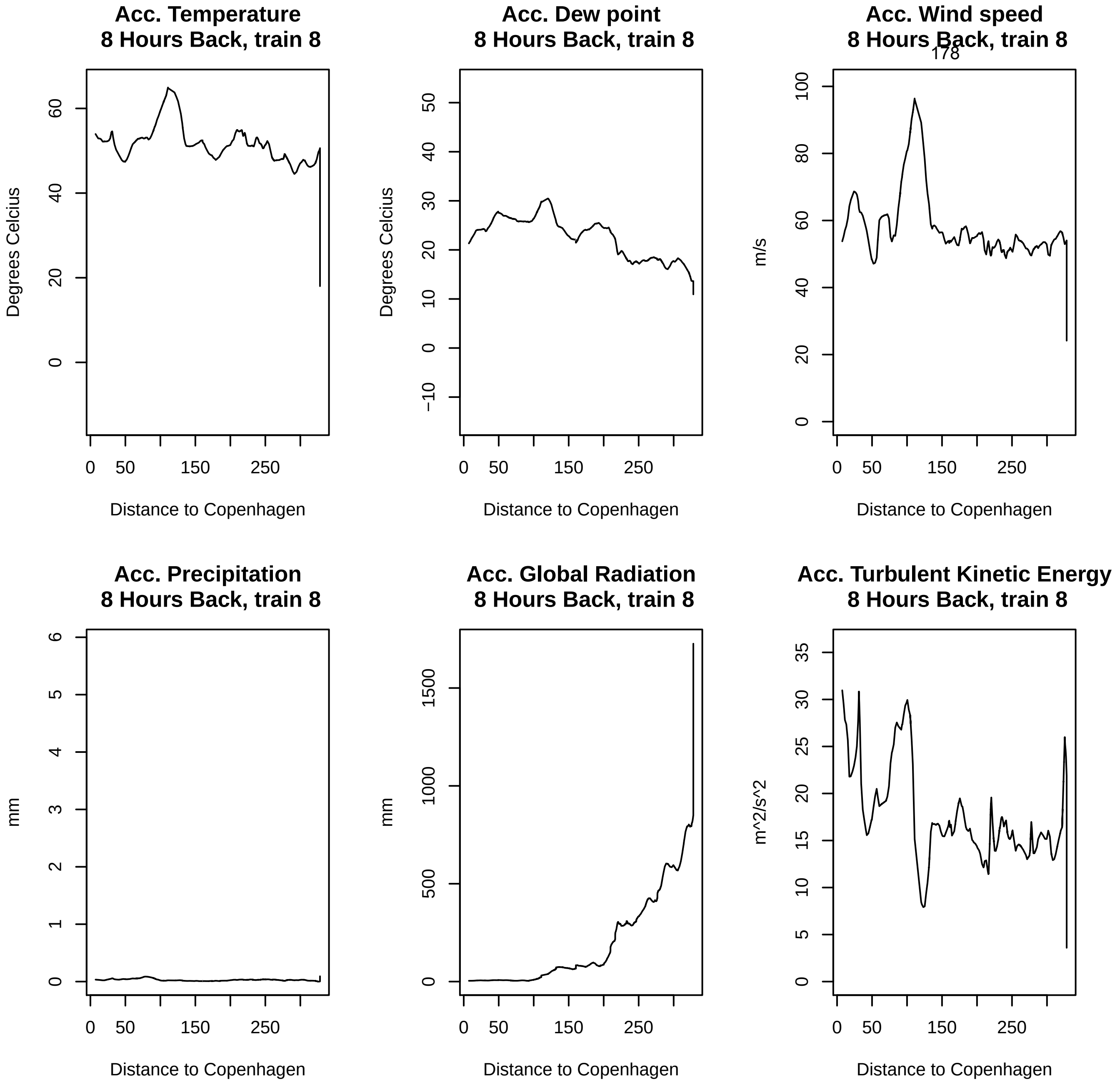
150
250
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 8
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 8
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 8
178
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 8
mm
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3
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5
6
0
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150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 8
mm
0
500
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1500
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50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 8
m^2/s^2
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30
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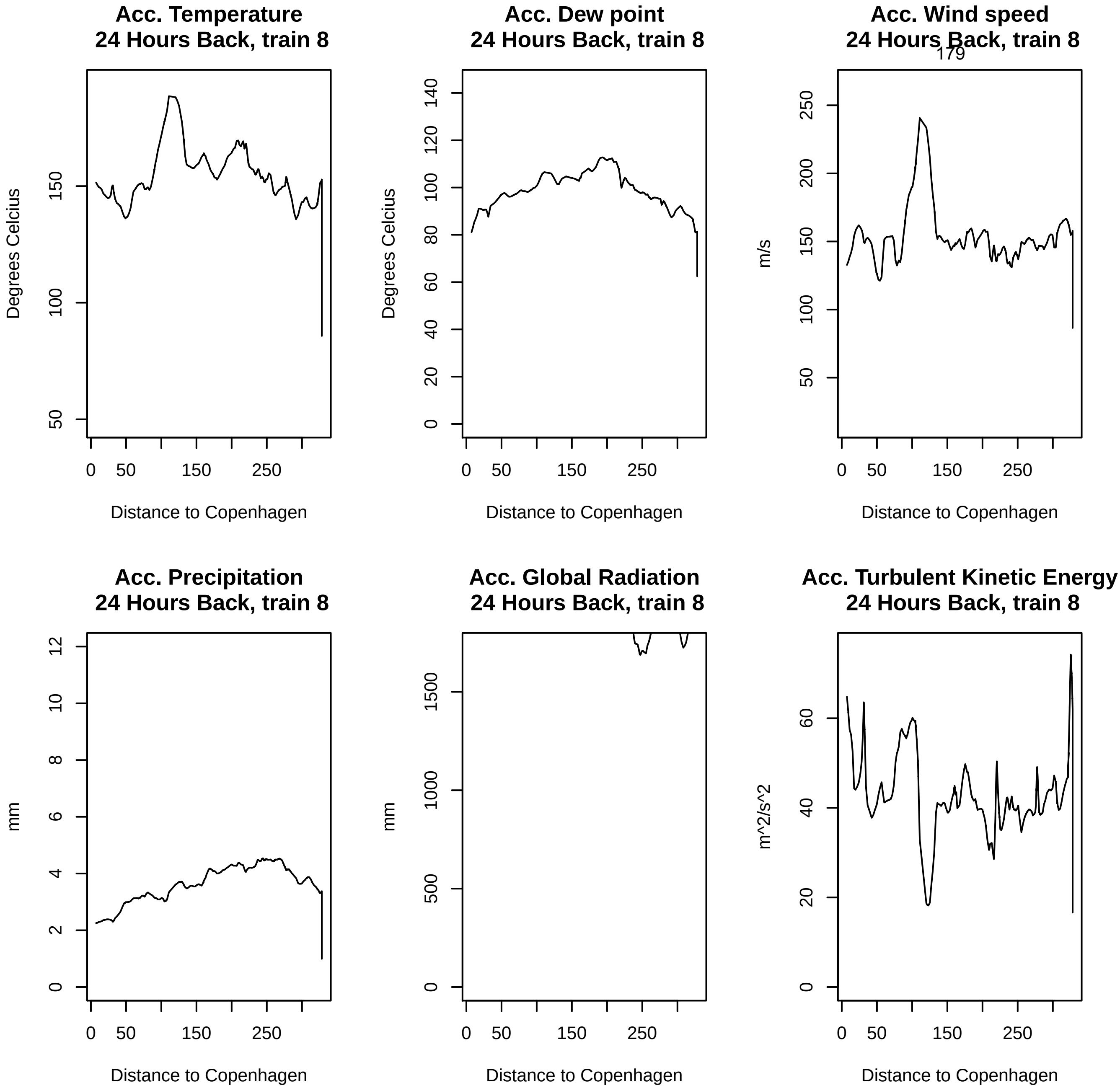
150
250
Distance to Copenhagen


Acc. Temperature
24 Hours Back, train 8
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 8
Degrees Celcius
0
20
40
60
80
100
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140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 8
179
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 8
mm
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2
4
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8
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150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 8
mm
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500
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1500
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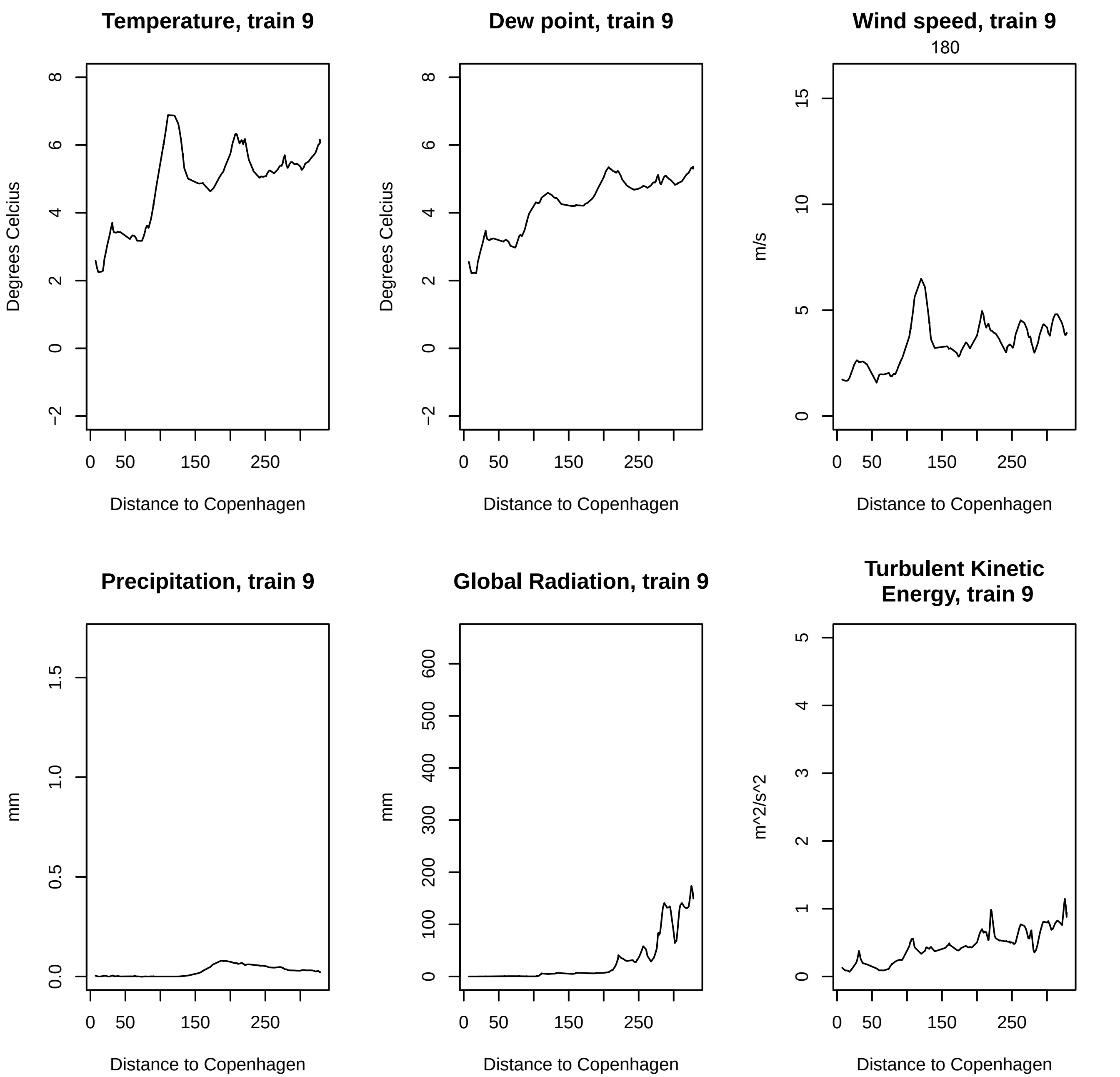
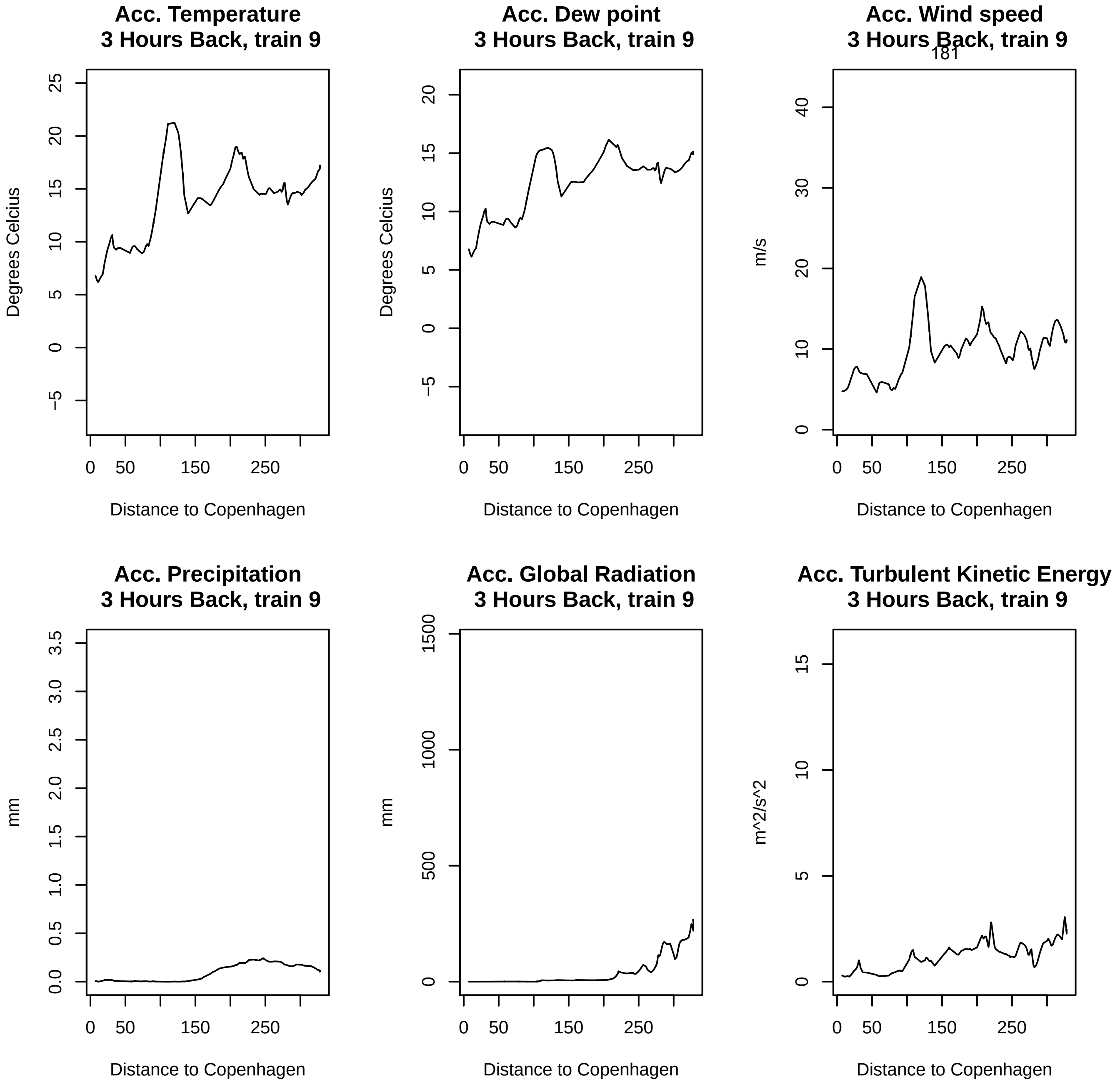
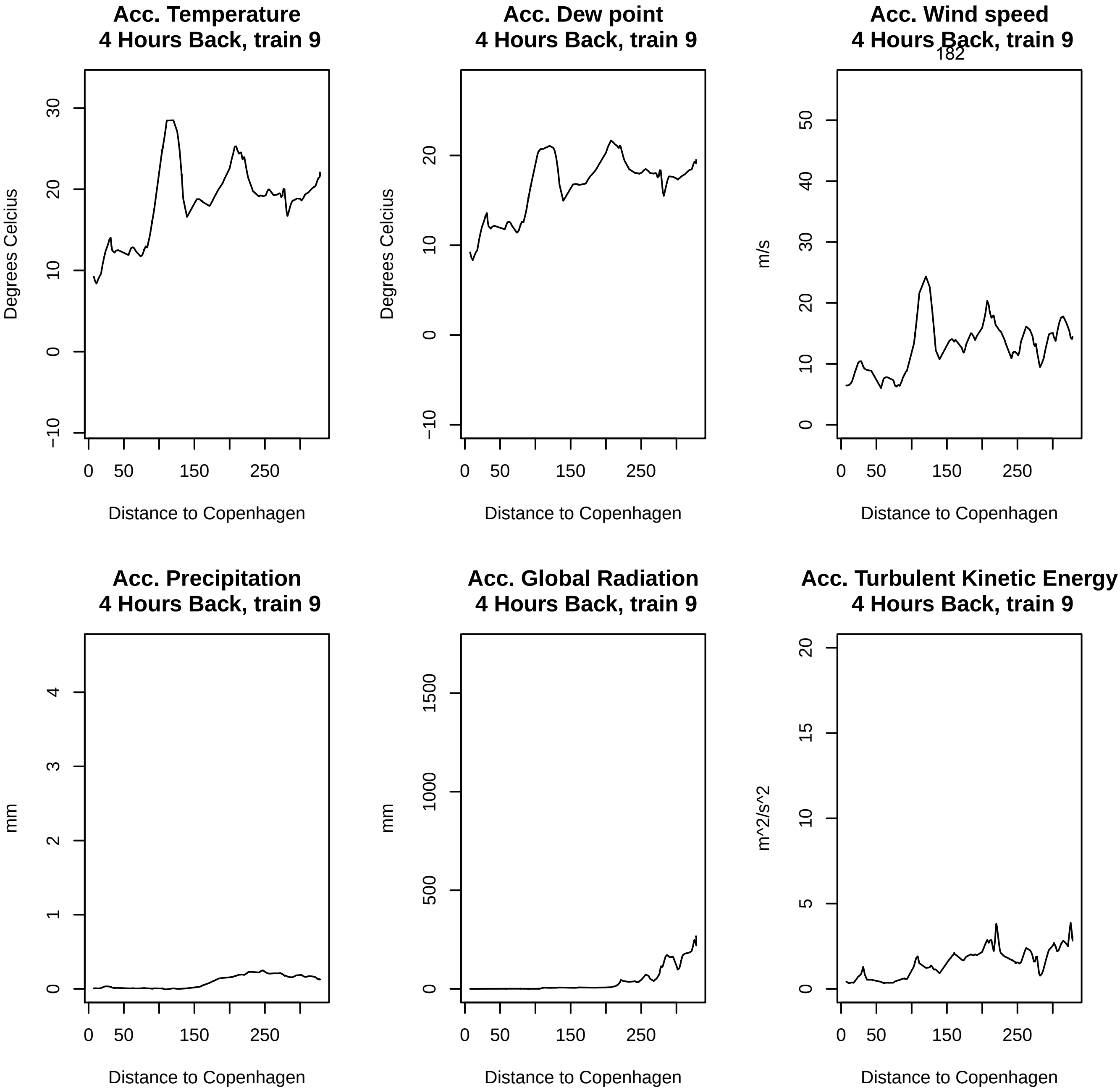
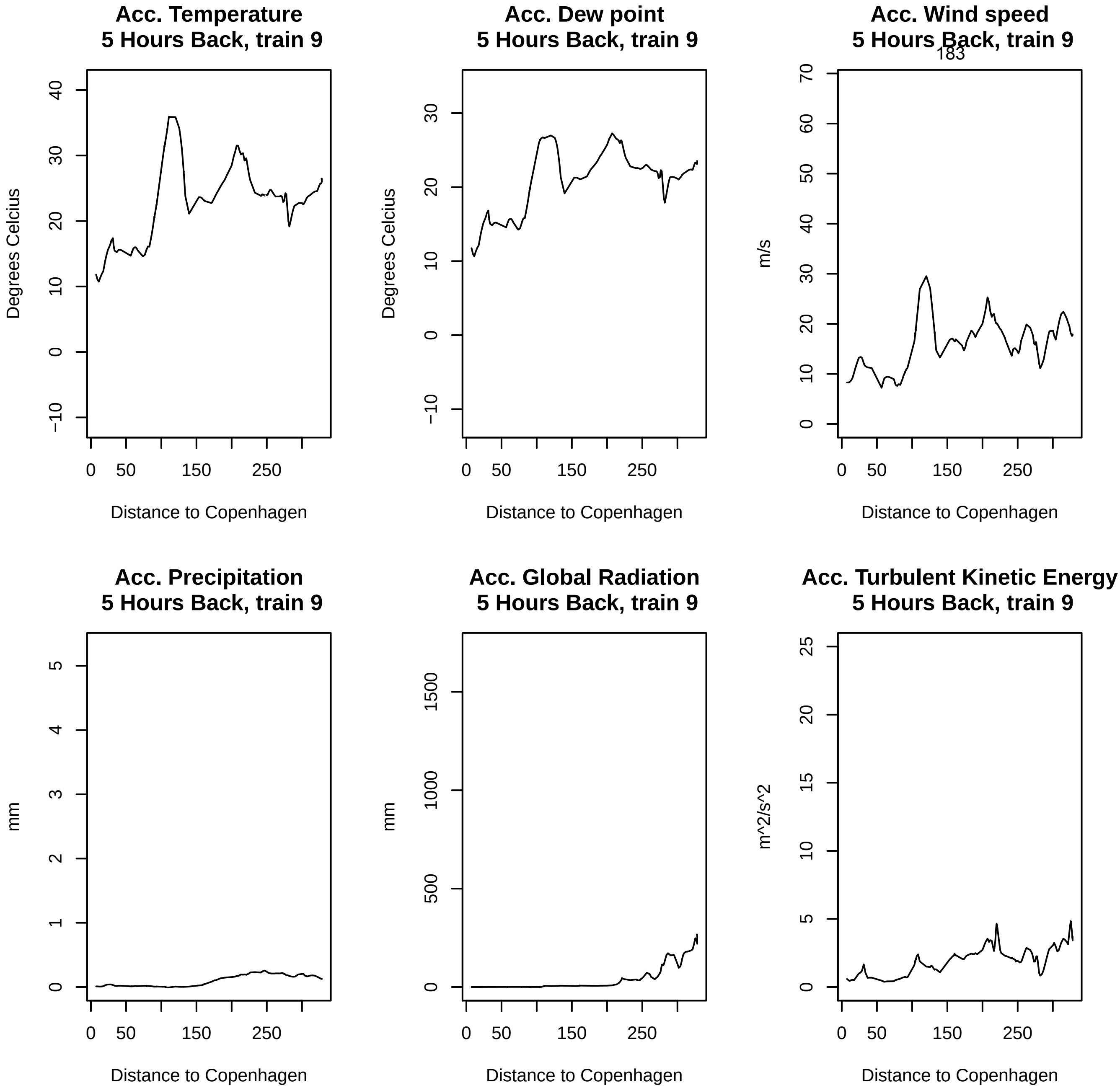
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 8
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen



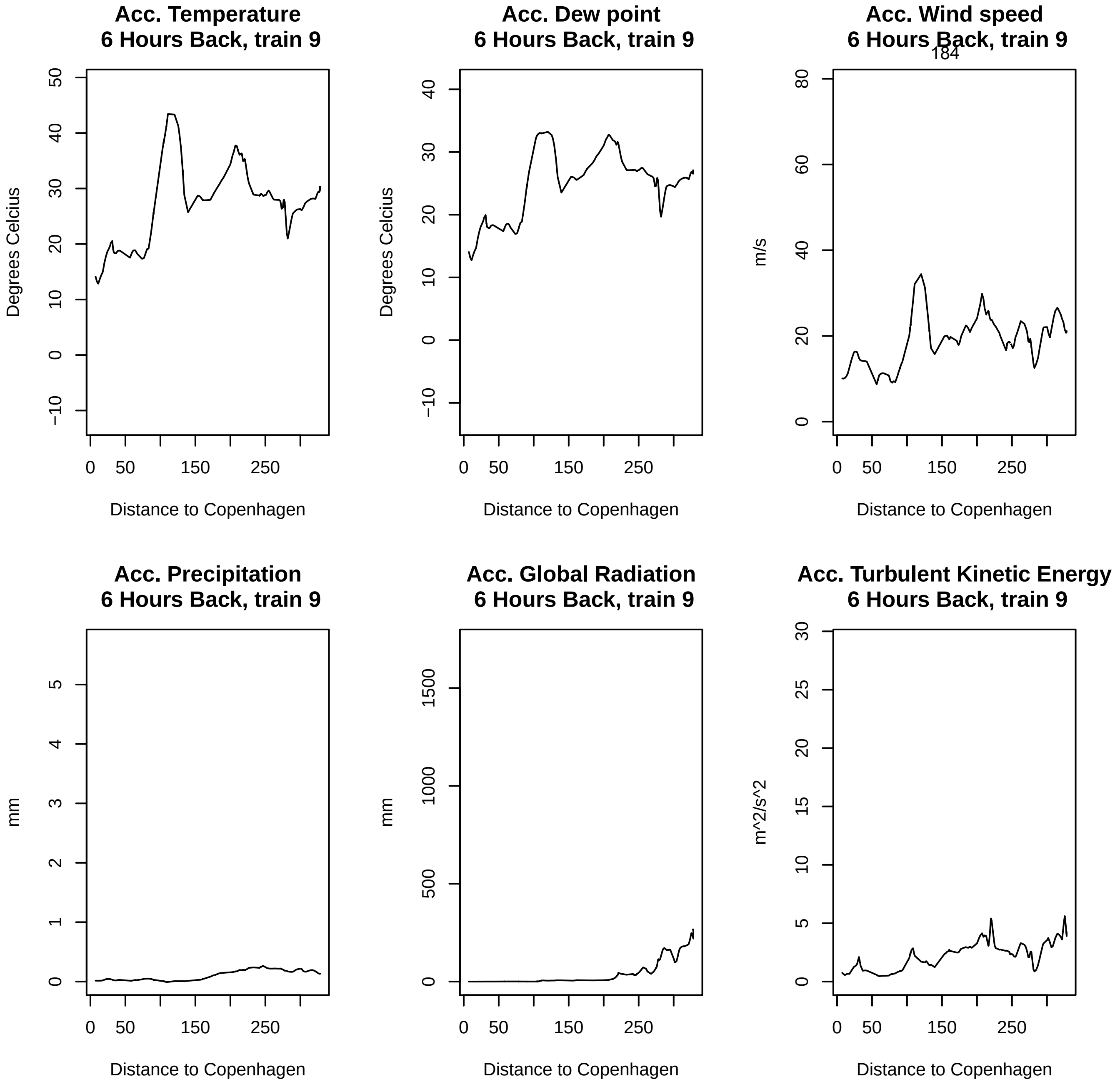
Temperature, train 9
Degrees Celcius
Distance to Copenhagen
Dew point, train 9
Degrees Celcius
Distance to Copenhagen
Wind speed, train 9
180
m/s
Distance to Copenhagen
Precipitation, train 9
mm
Distance to Copenhagen
Global Radiation, train 9
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 9
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 9
Degrees Celcius
−5 0 5 10 15 20 25
0 50 150 250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 9
Degrees Celcius
−5 0 5 10 15 20
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 9
m/s
0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 9
mm
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 9
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 9
m^2/s^2
0 5 10 15
0 50 150 250
Distance to Copenhagen

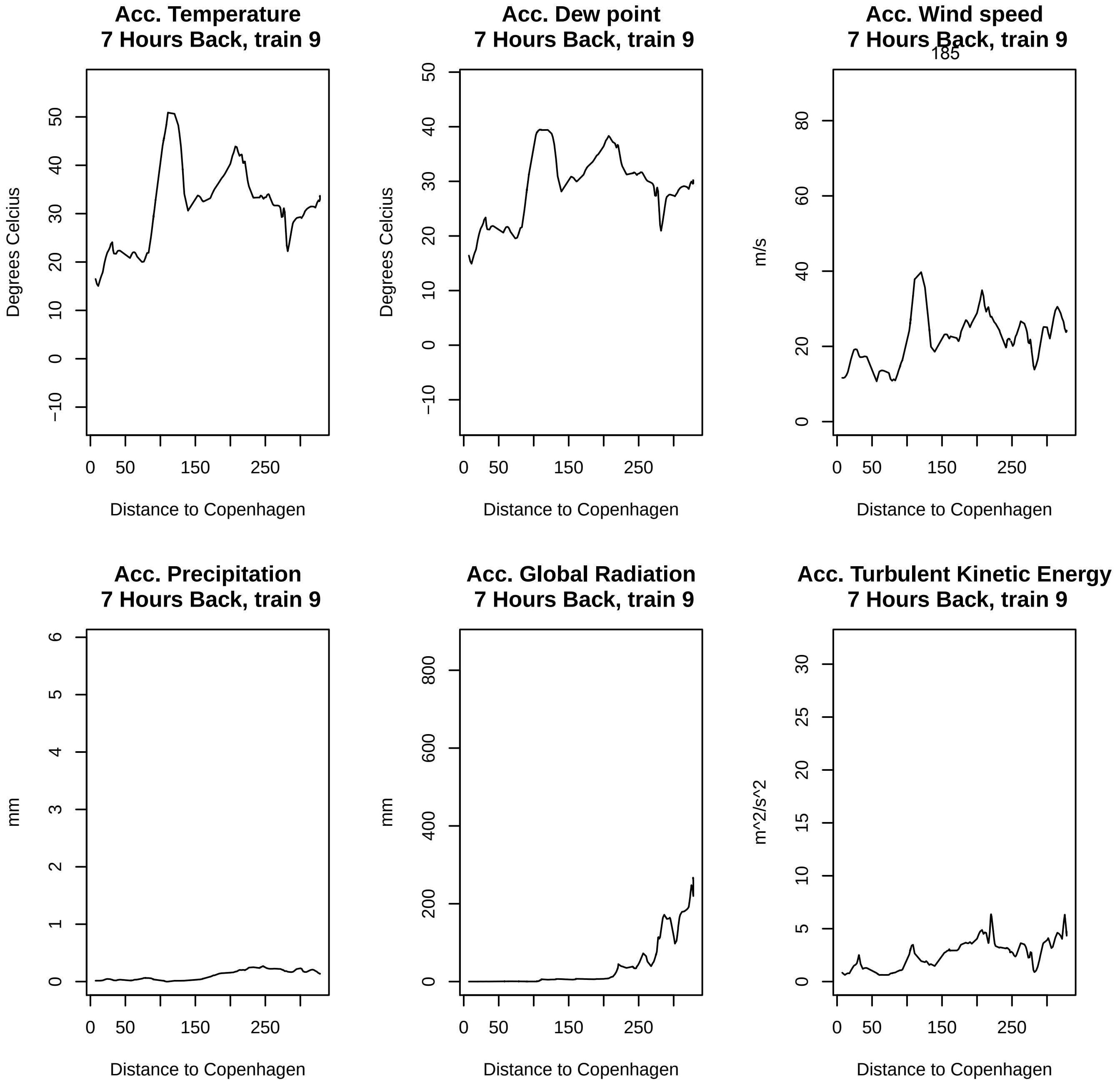

Acc. Temperature
4 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 9
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 9
m^2/s^2
Distance to Copenhagen

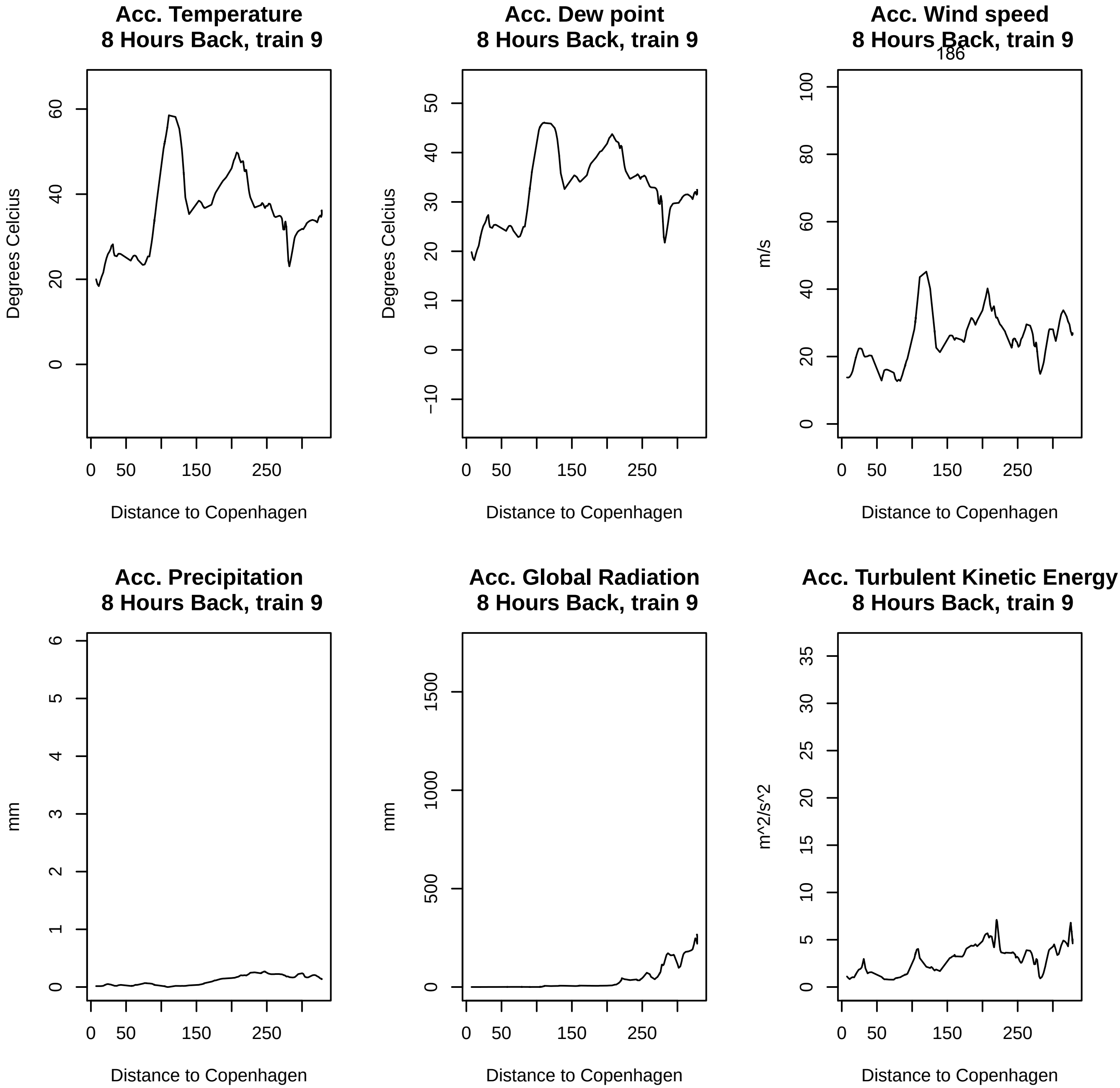


Acc. Temperature
5 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 9
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 9
m^2/s^2
Distance to Copenhagen



Acc. Temperature
6 Hours Back, train 9
Degrees Celcius
−10 0 10 20 30 40 50
0 50 150 250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 9
Degrees Celcius
−10 0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 9
m/s
0 20 40 60 80
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 9
mm
0 1 2 3 4 5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 9
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 9
m^2/s^2
0 5 10 15 20 25 30
0 50 150 250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 9
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 9
m^2/s^2
Distance to Copenhagen



Acc. Temperature
8 Hours Back, train 9
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 9
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 9
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 9
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 9
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 9
m^2/s^2
0
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10
15
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25
30
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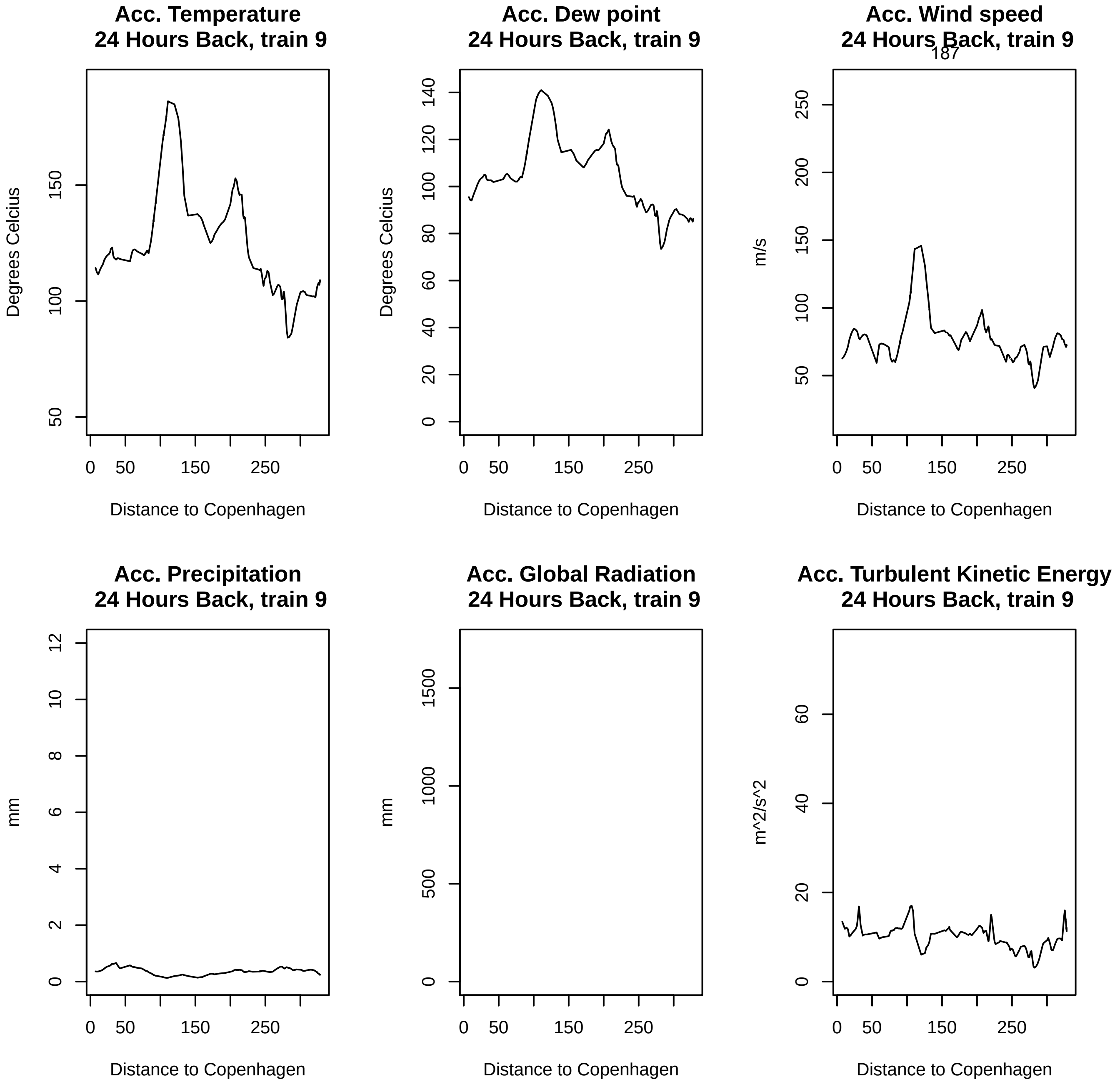
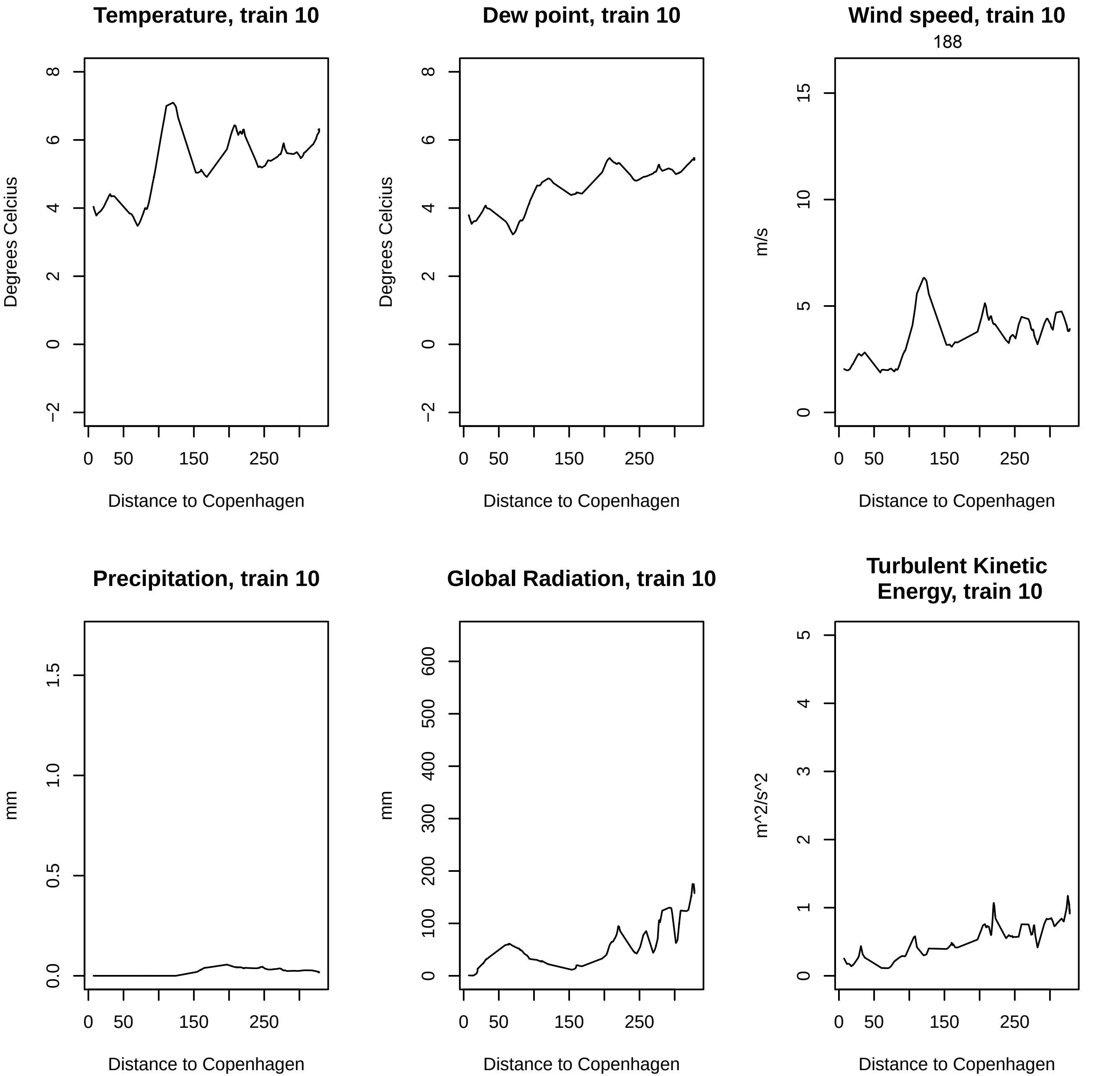
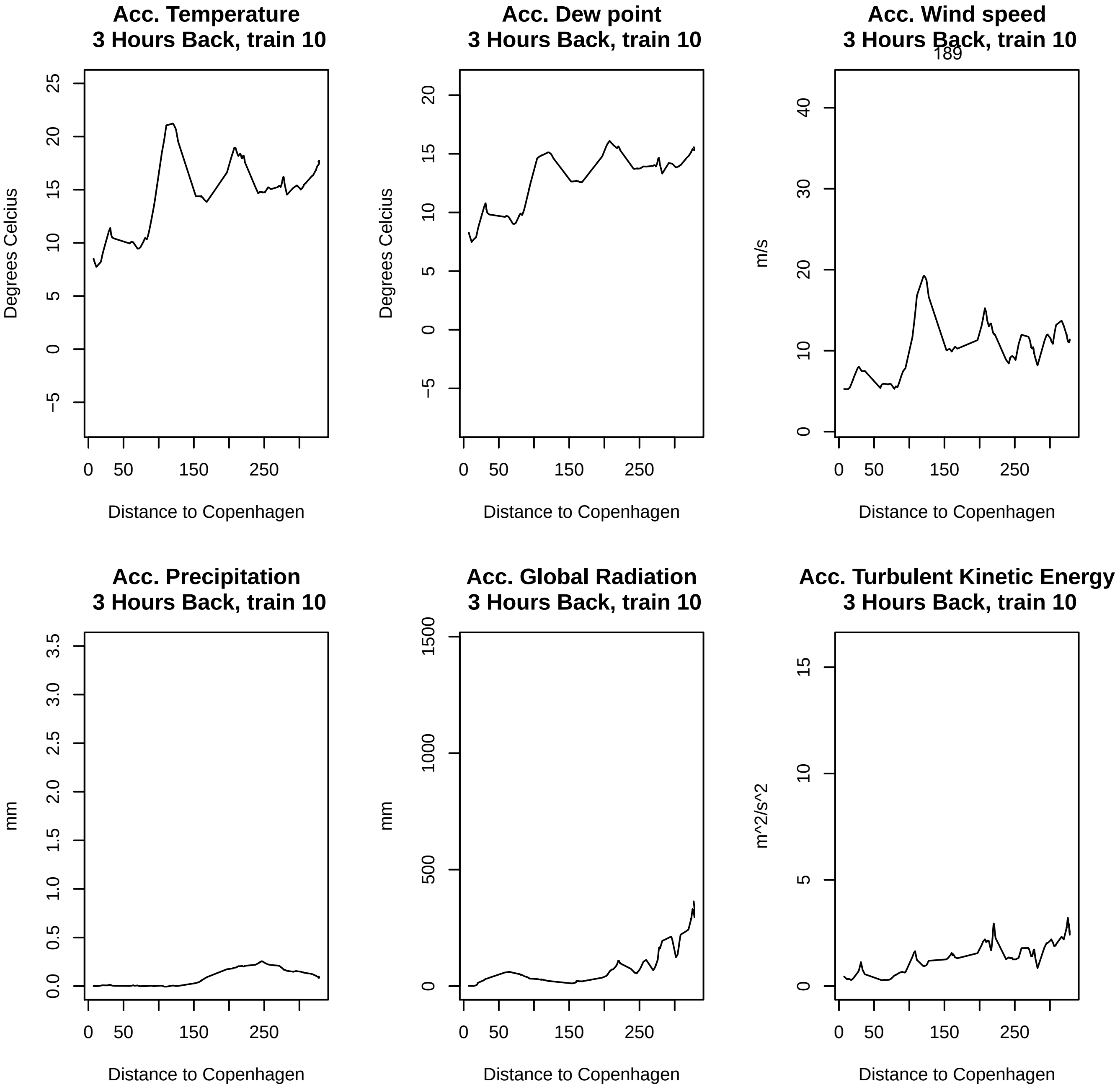
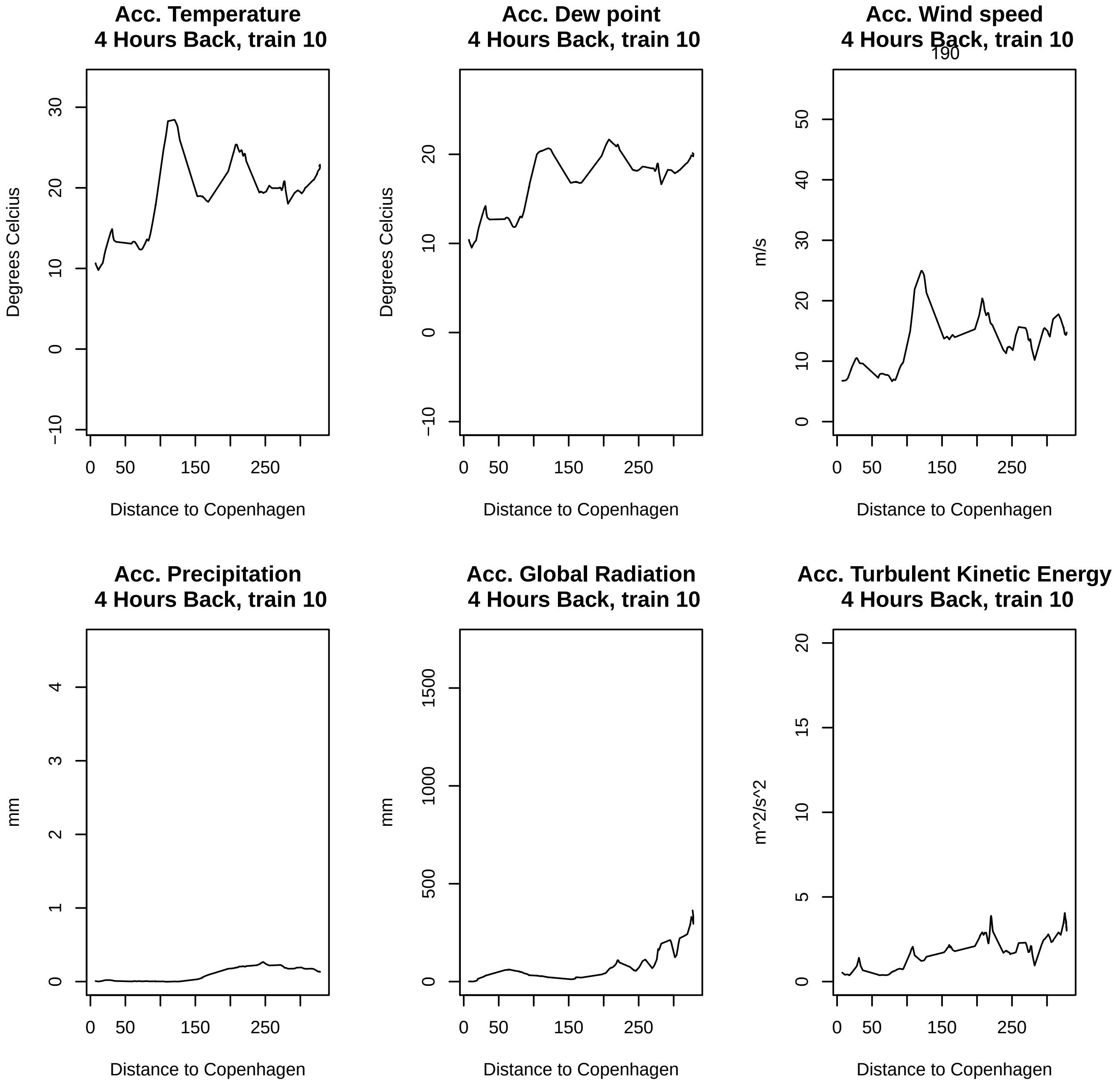
0
50
150
250
Distance to Copenhagen

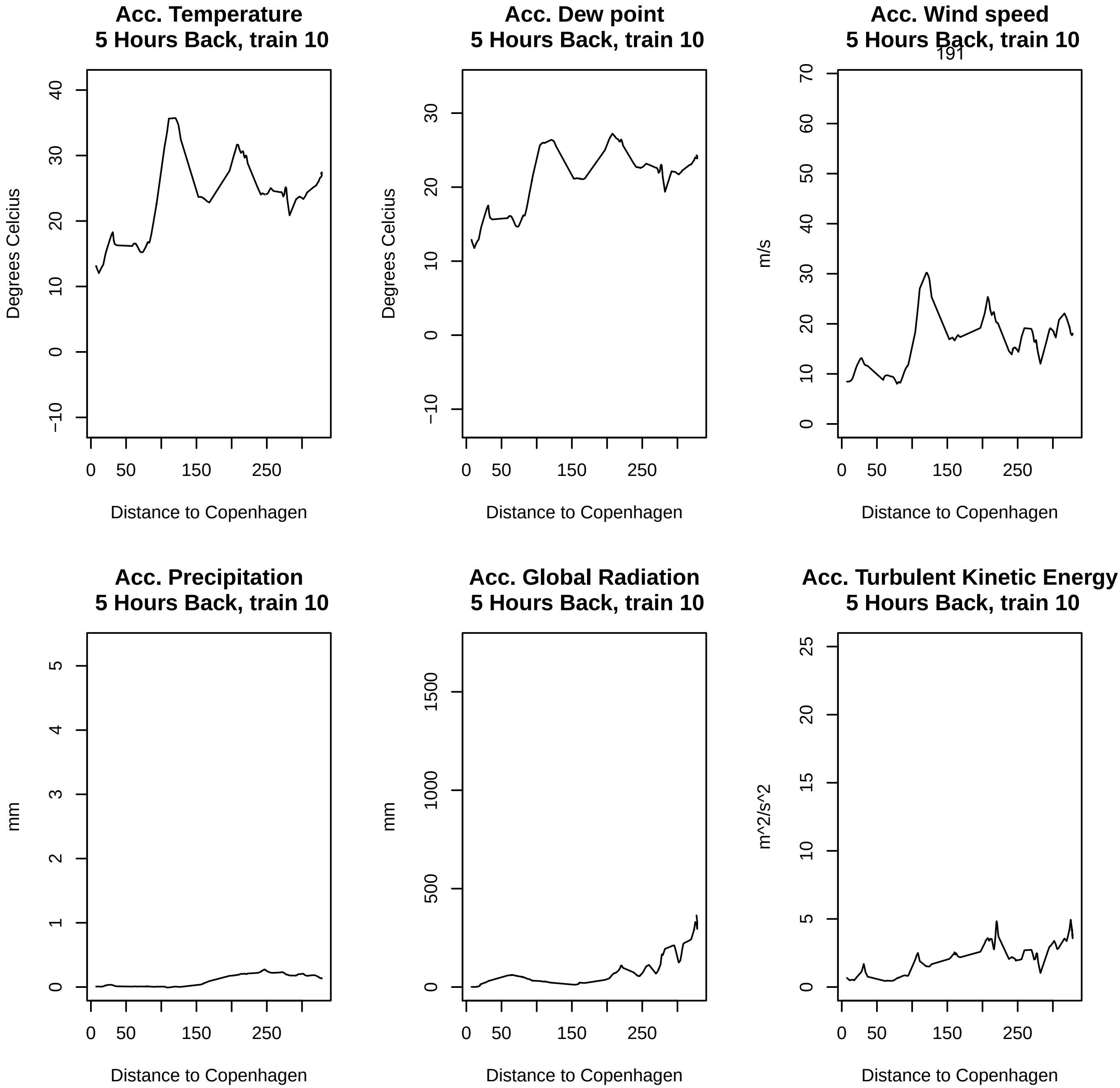

Acc. Temperature
24 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 9
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 9
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 9
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 9
m^2/s^2
Distance to Copenhagen

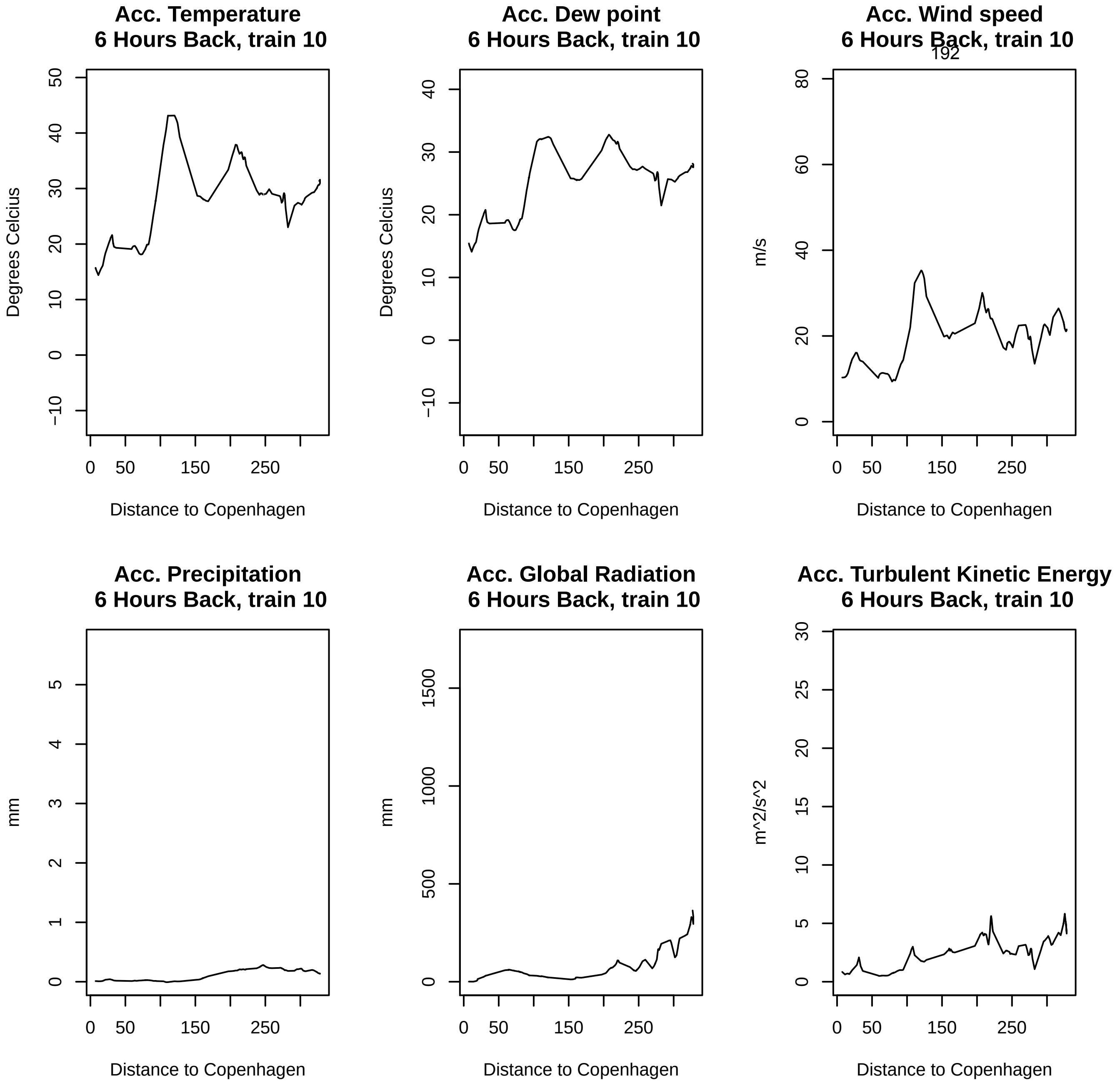


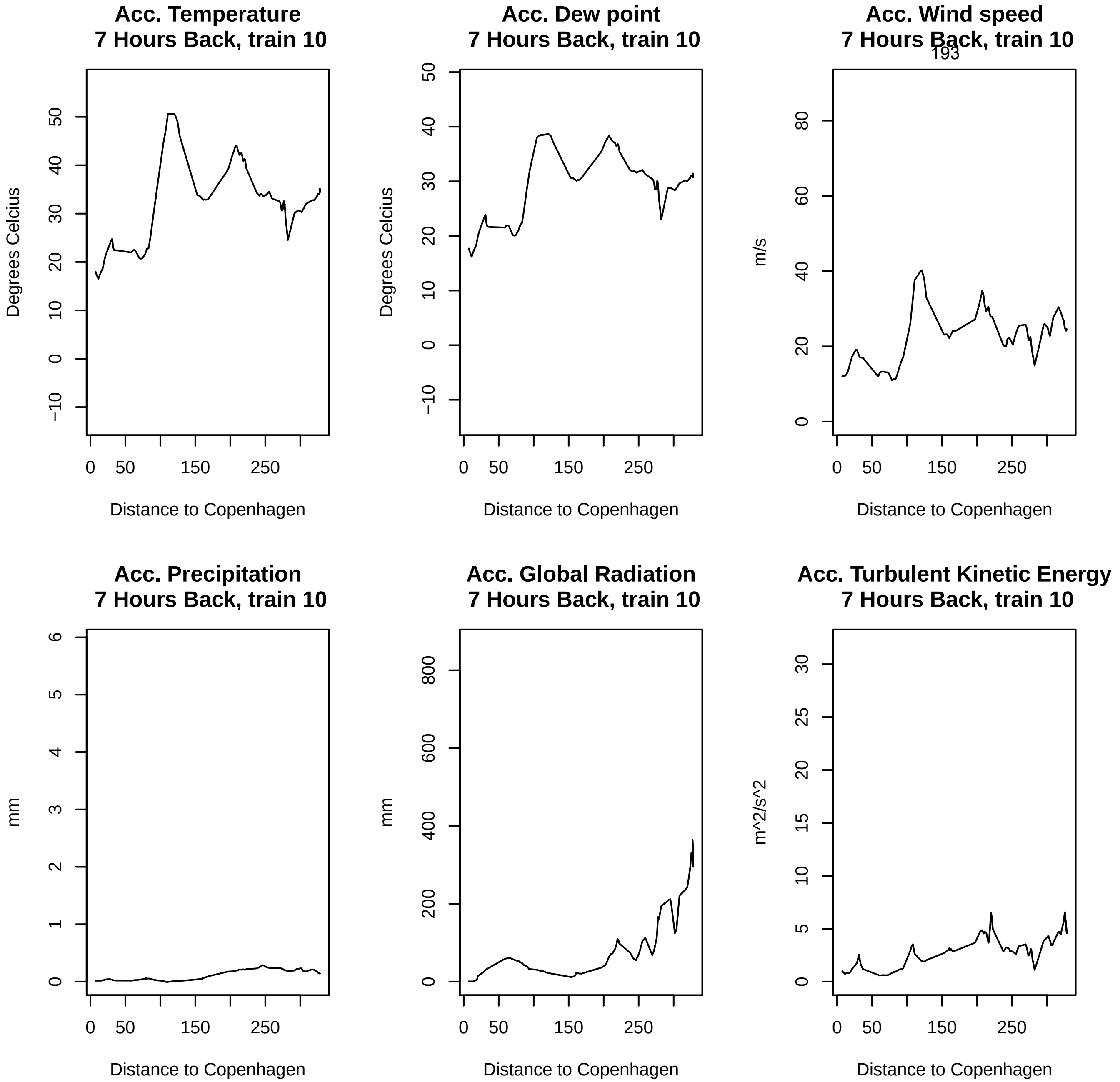
Temperature, train 10
Degrees Celcius
−2
0
2
4
6
8
Distance to Copenhagen
0
50
150
250
Dew point, train 10
Degrees Celcius
Distance to Copenhagen
Wind speed, train 10
m/s
0
5
10
15
Distance to Copenhagen
Precipitation, train 10
mm
0.0
0.5
1.0
1.5
Distance to Copenhagen
Global Radiation, train 10
mm
0
100
200
300
400
500
600
Distance to Copenhagen
Turbulent Kinetic Energy, train 10
m^2/s^2
0
1
2
3
4
5
Distance to Copenhagen

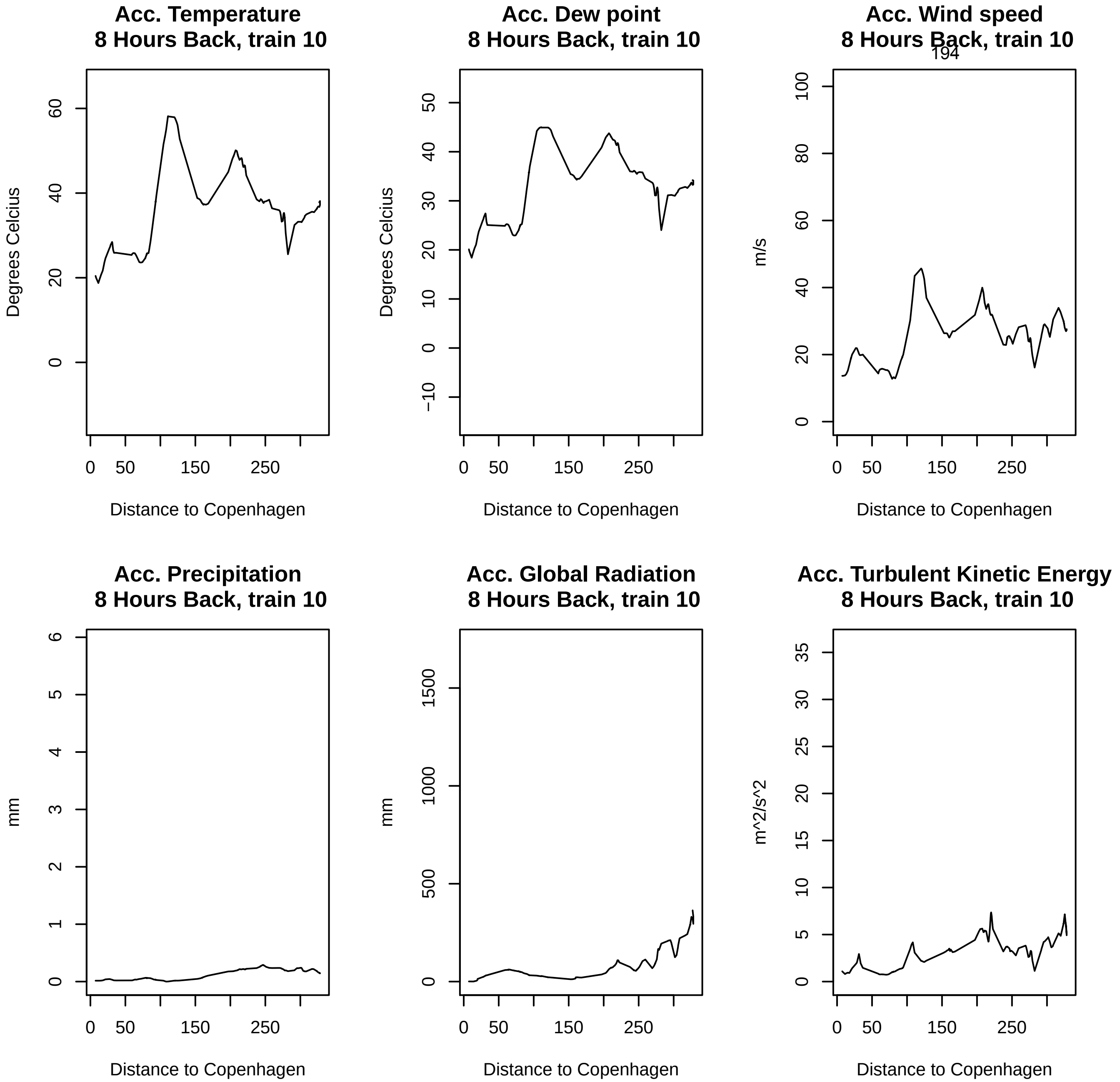

Acc. Temperature
3 Hours Back, train 10
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 10
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 10
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 10
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 10
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 10
m^2/s^2
Distance to Copenhagen

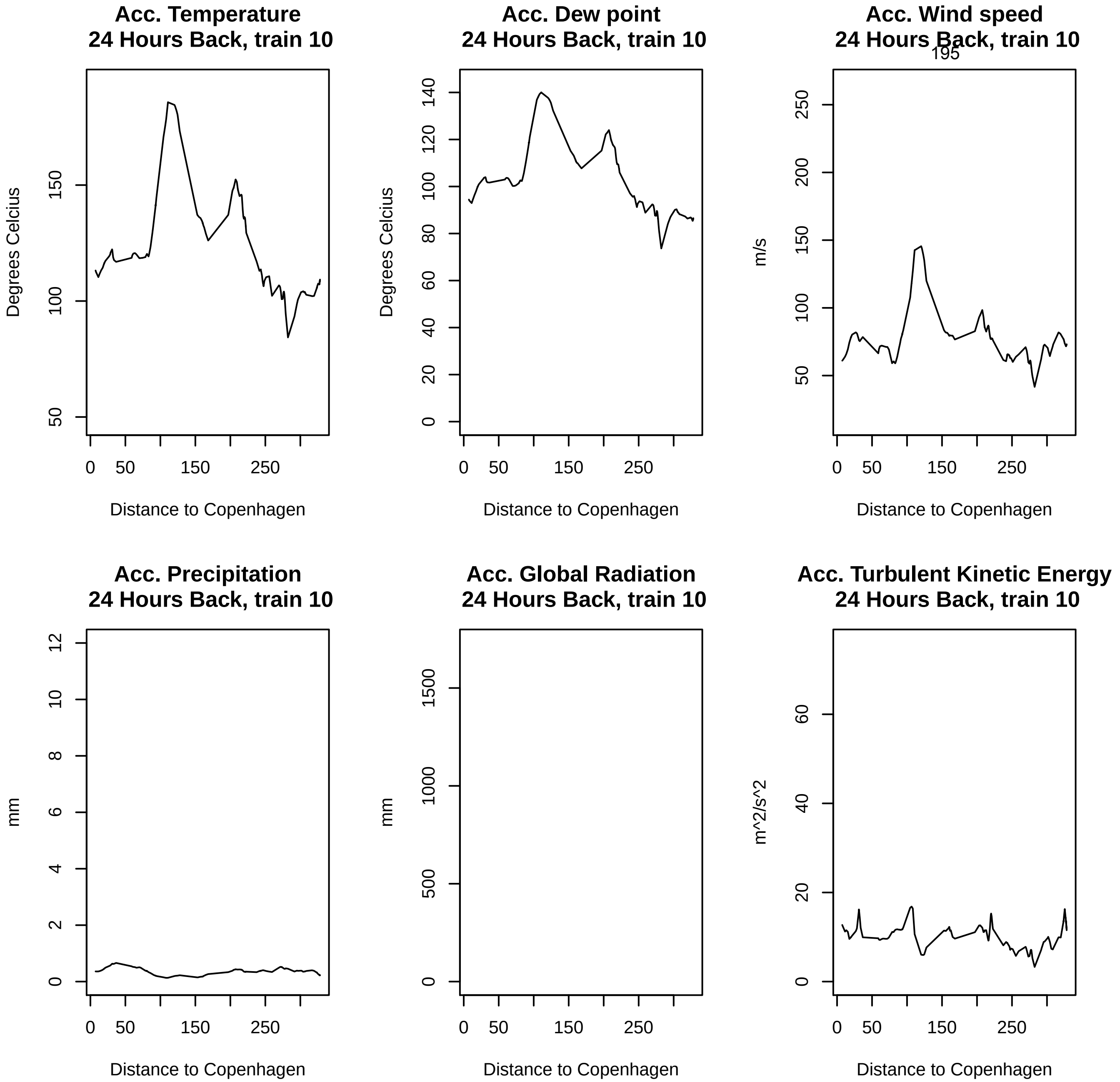

Acc. Temperature
4 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 10
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 10
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 10
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 10
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 10
m^2/s^2
0
5
10
15
20
0
50
150
250
Distance to Copenhagen

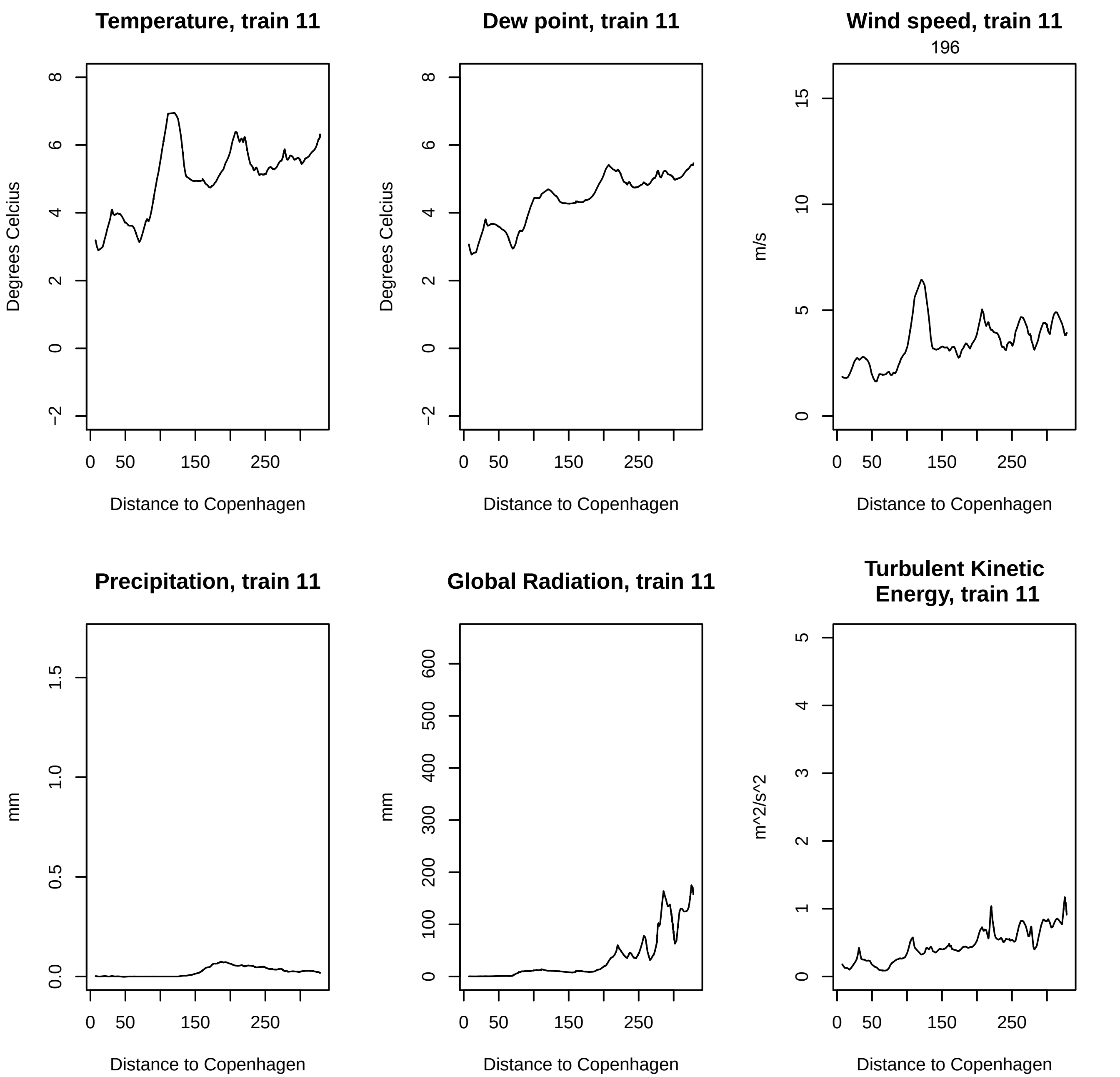

Acc. Temperature
5 Hours Back, train 10
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 10
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 10
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 10
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 10
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 10
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
40
Acc. Wind speed
6 Hours Back, train 10
m/s
0
20
40
60
80
Acc. Precipitation
6 Hours Back, train 10
mm
0
1
2
3
4
5
Acc. Global Radiation
6 Hours Back, train 10
mm
0
500
1000
1500
Acc. Turbulent Kinetic Energy
6 Hours Back, train 10
m^2/s^2
0
5
10
15
20
25
30

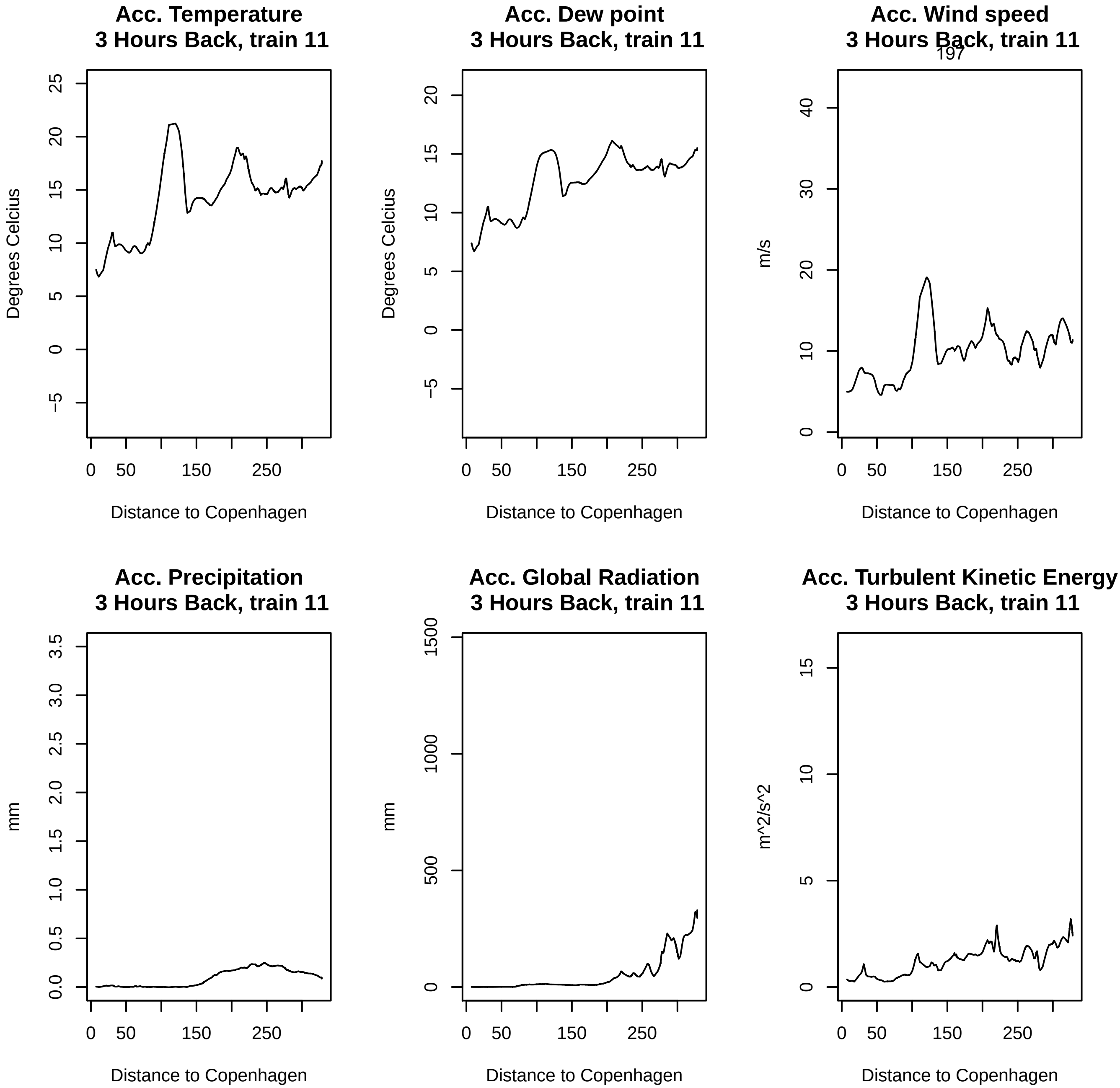

Acc. Temperature
7 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 10
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 10
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 10
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 10
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

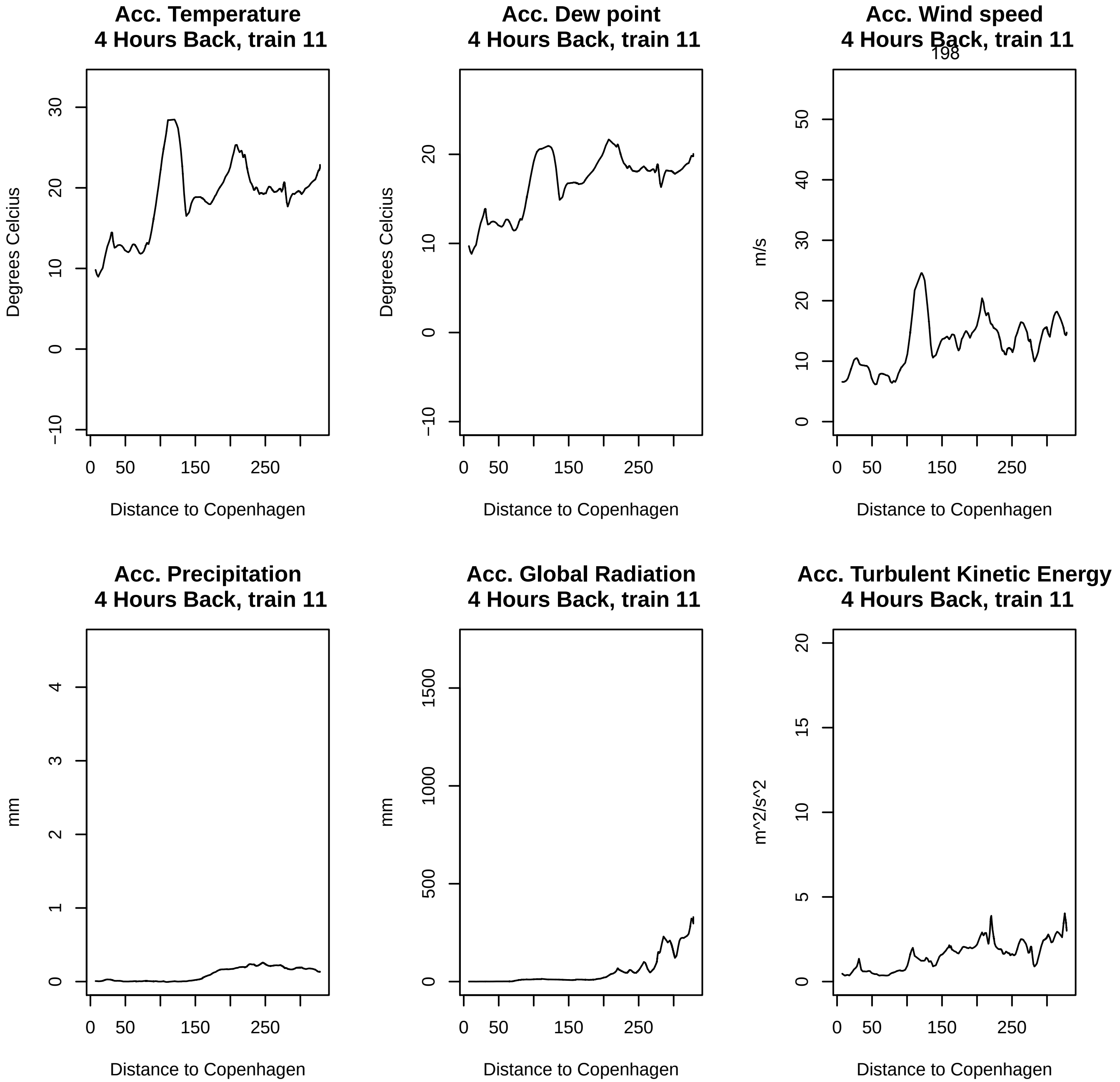

Acc. Temperature
8 Hours Back, train 10
Degrees Celcius
0
20
40
60
Distance to Copenhagen
0
50
150
250
Acc. Dew point
8 Hours Back, train 10
Degrees Celcius
−10
0
10
20
30
40
50
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 10
m/s
0
20
40
60
80
100
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 10
mm
0
1
2
3
4
5
6
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 10
mm
0
500
1000
1500
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 10
m^2/s^2
0
5
10
15
20
25
30
35
Distance to Copenhagen

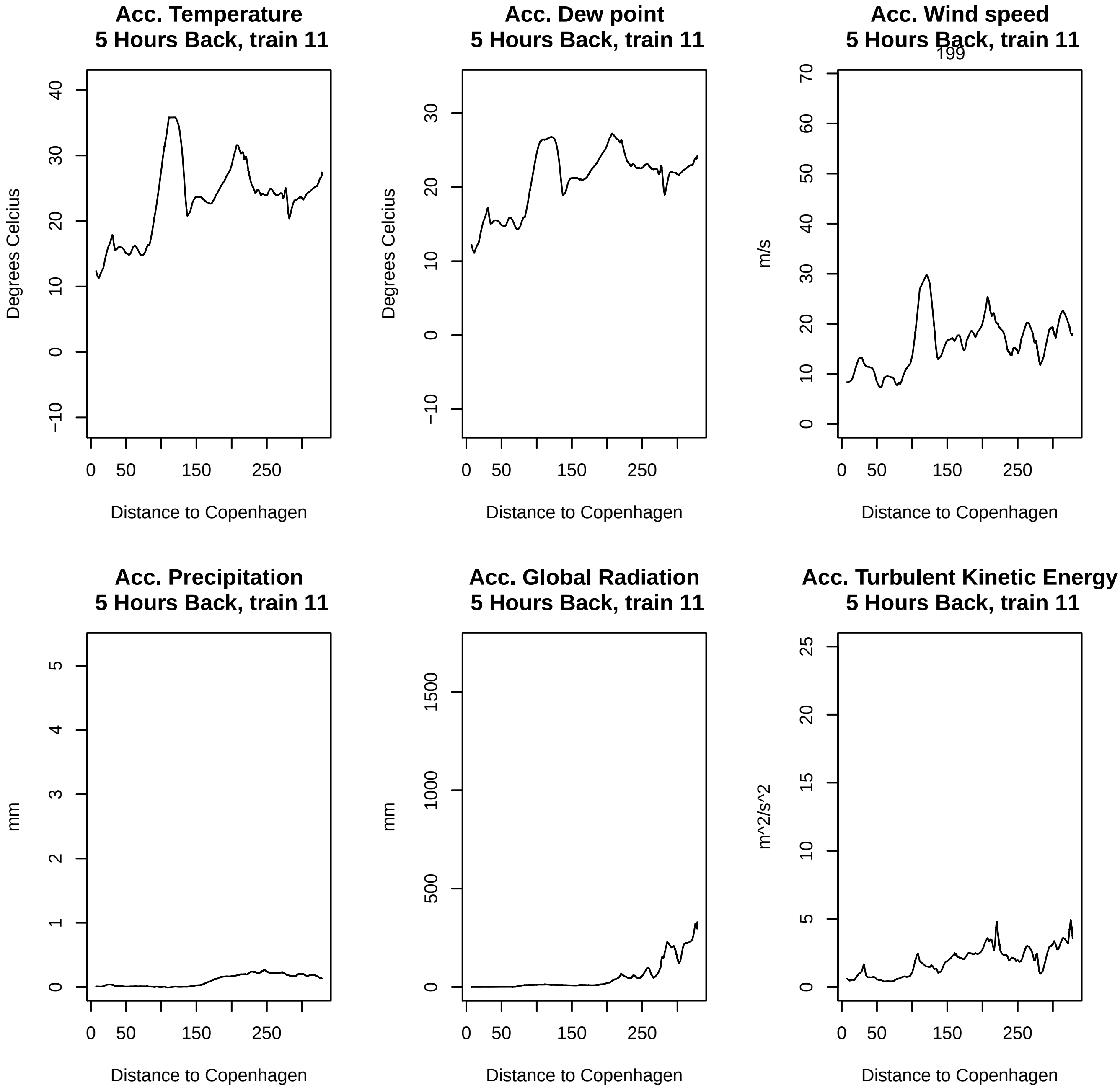

Acc. Temperature
24 Hours Back, train 10
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 10
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 10
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 10
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 10
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 10
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

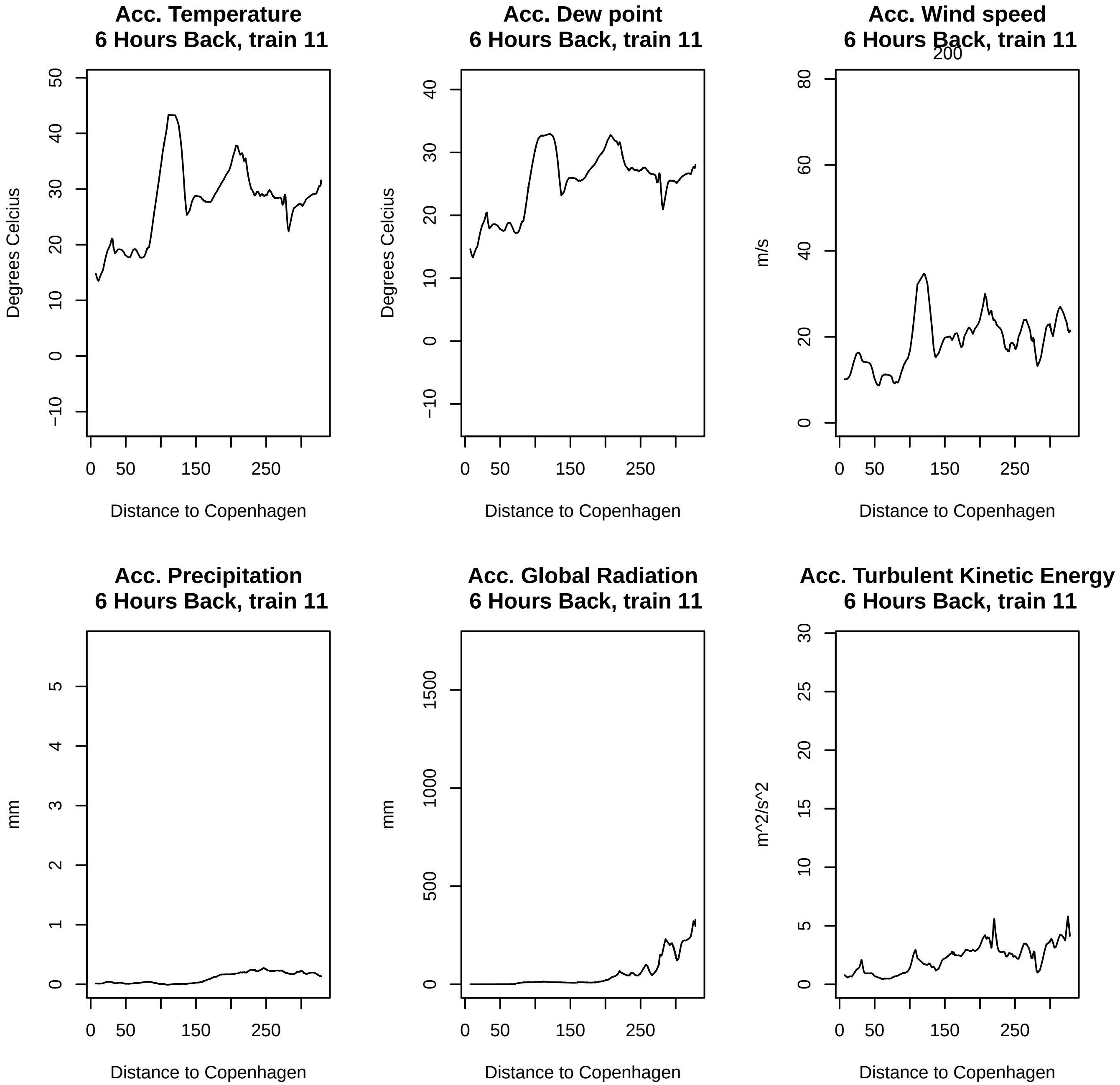


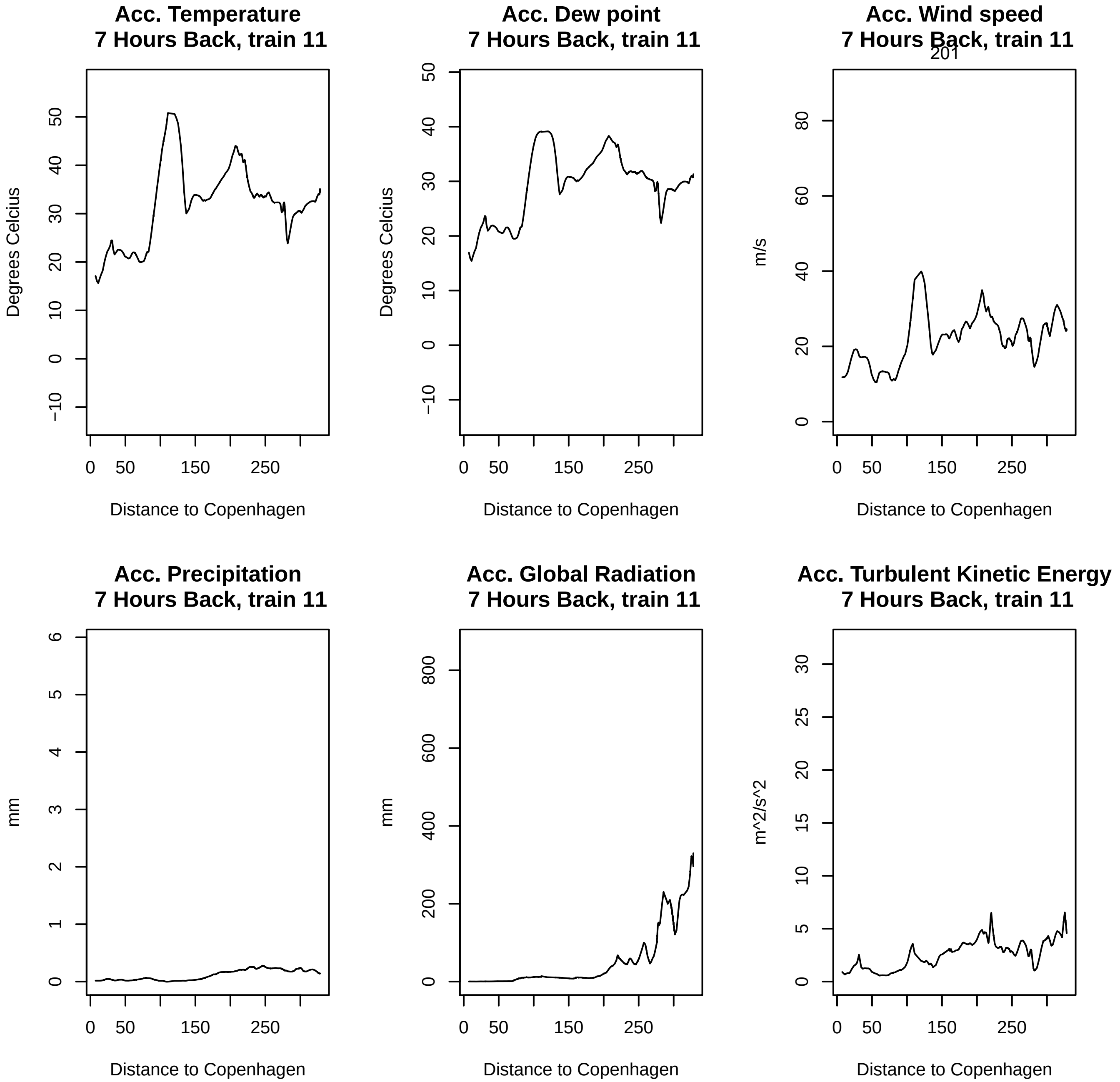
Temperature, train 11
Degrees Celcius
Dew point, train 11
Degrees Celcius
Wind speed, train 11
196
m/s
Precipitation, train 11
mm
Global Radiation, train 11
mm
Turbulent Kinetic Energy, train 11
m^2/s^2
Distance to Copenhagen

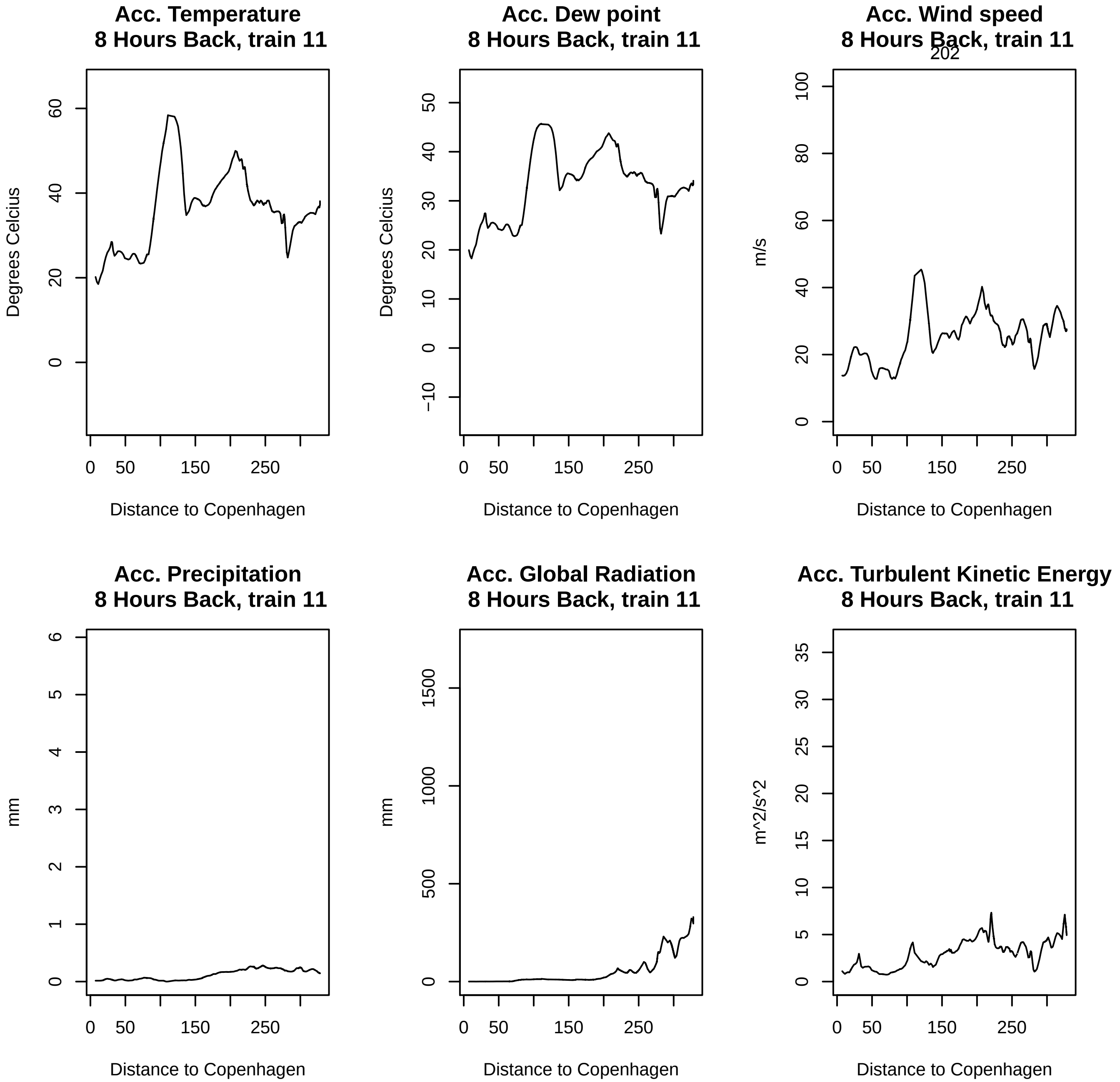

Acc. Temperature
3 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 11
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 11
m^2/s^2
Distance to Copenhagen

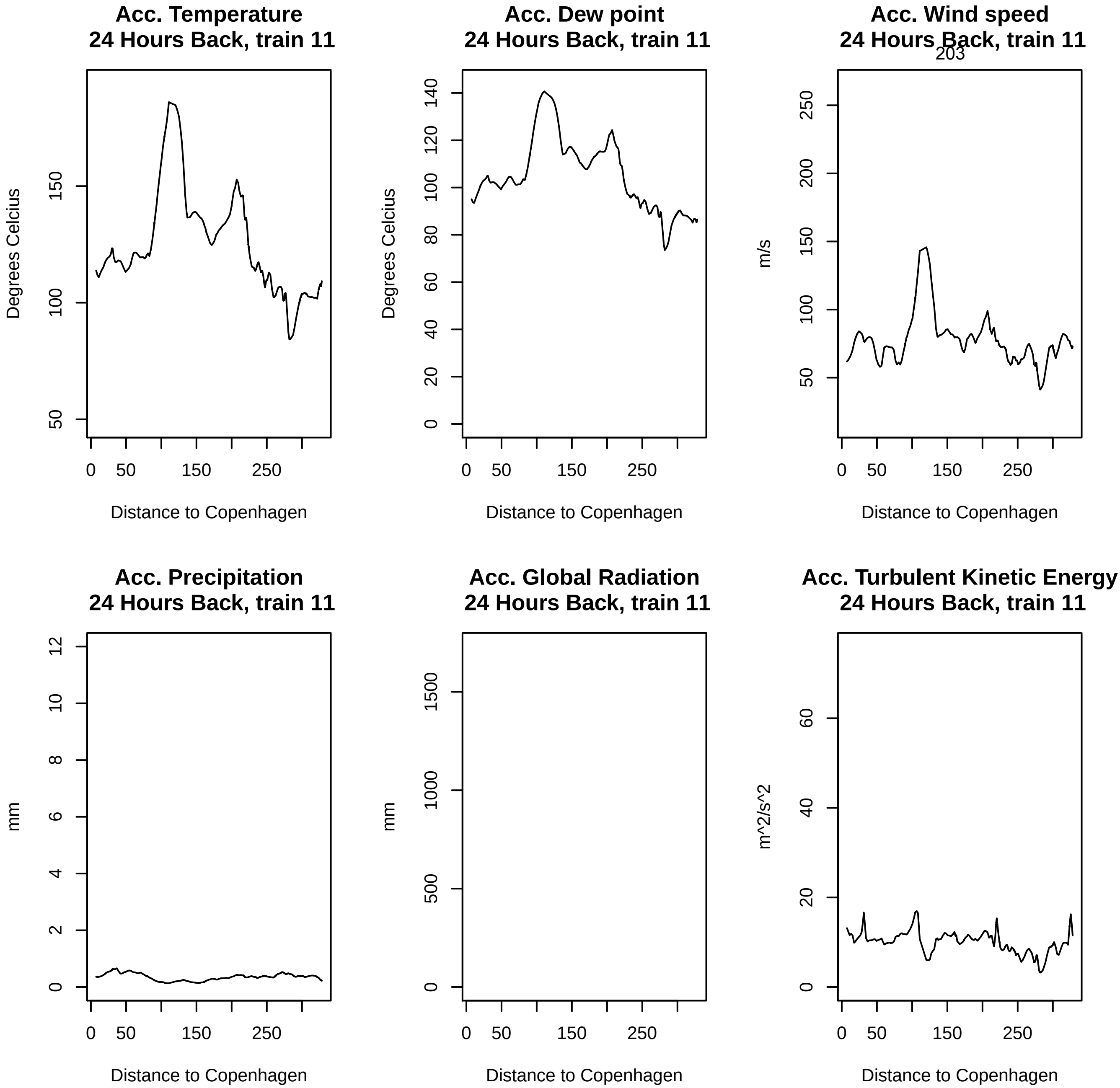

Acc. Temperature
4 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 11
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 11
m^2/s^2
Distance to Copenhagen

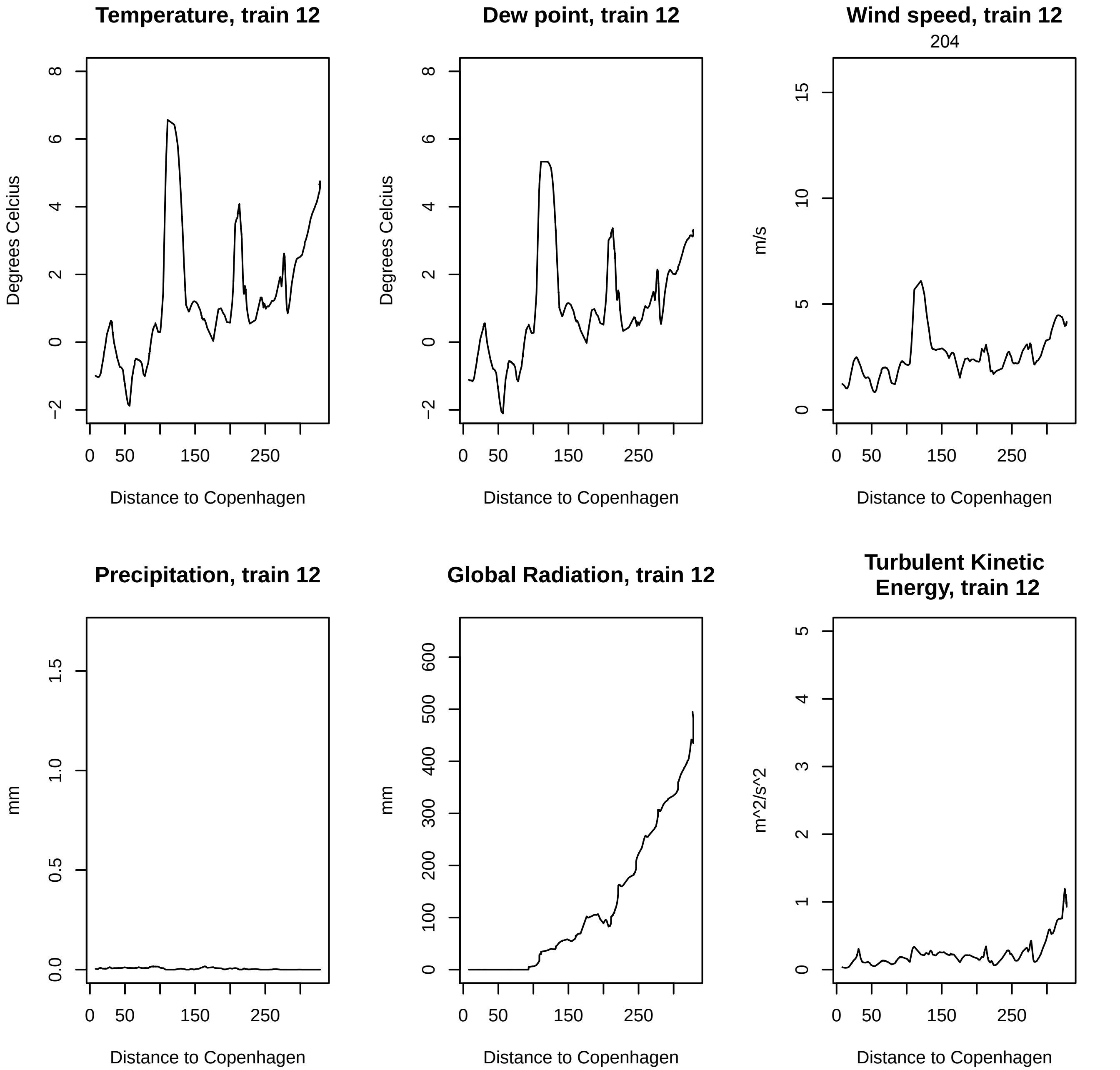

Acc. Temperature
5 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 11
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 11
m^2/s^2
Distance to Copenhagen

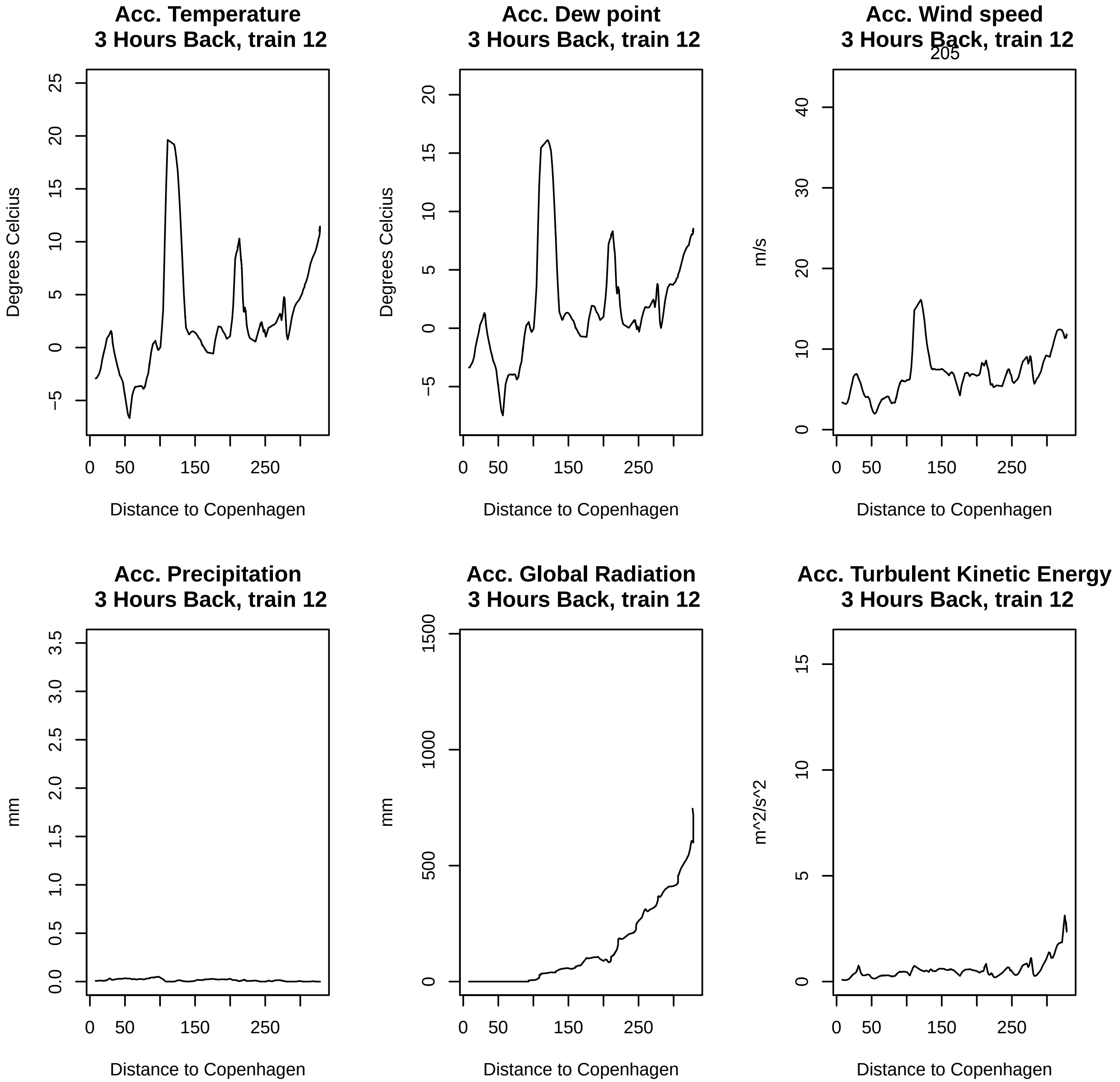

Acc. Temperature
6 Hours Back, train 11
Degrees Celcius
−10 0 10 20 30 40 50
0 50 150 250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 11
Degrees Celcius
−10 0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 11
200
m/s
0 20 40 60 80
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 11
mm
0 1 2 3 4 5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 11
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 11
m^2/s^2
0 5 10 15 20 25 30
0 50 150 250
Distance to Copenhagen

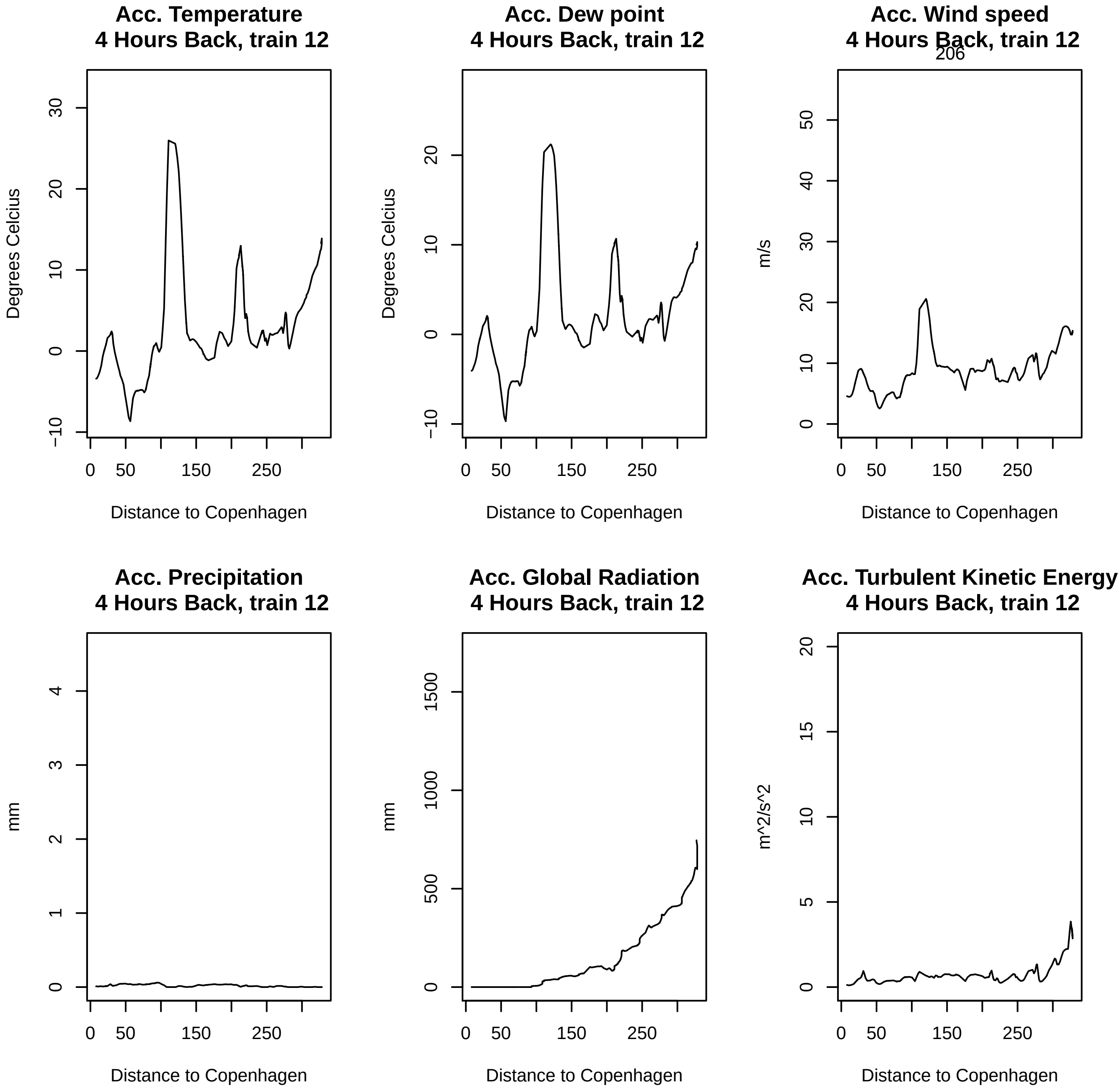

Acc. Temperature
7 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 11
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 11
m^2/s^2
Distance to Copenhagen

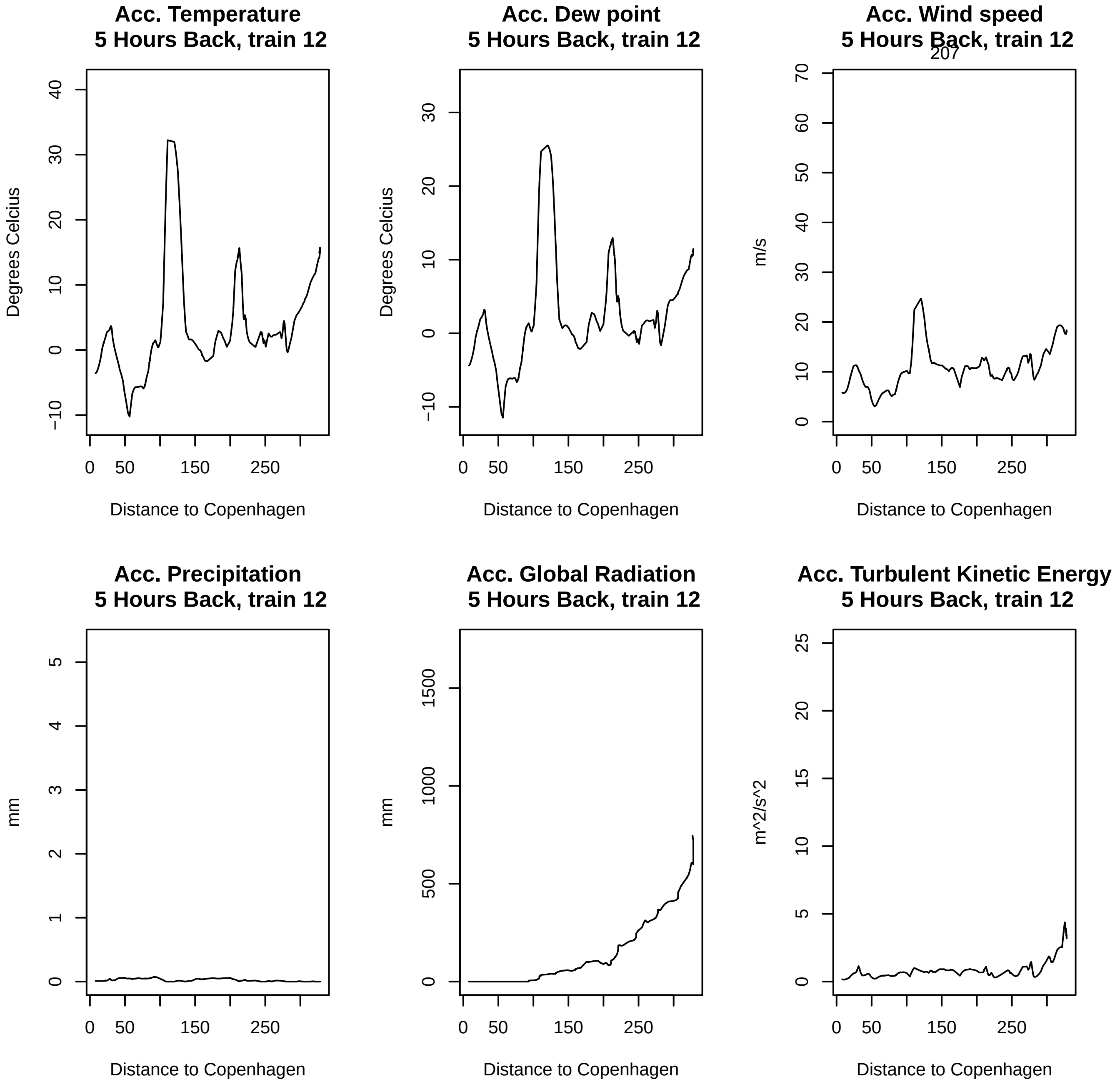

Acc. Temperature
8 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 11
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 11
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 11
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 11
m^2/s^2
Distance to Copenhagen

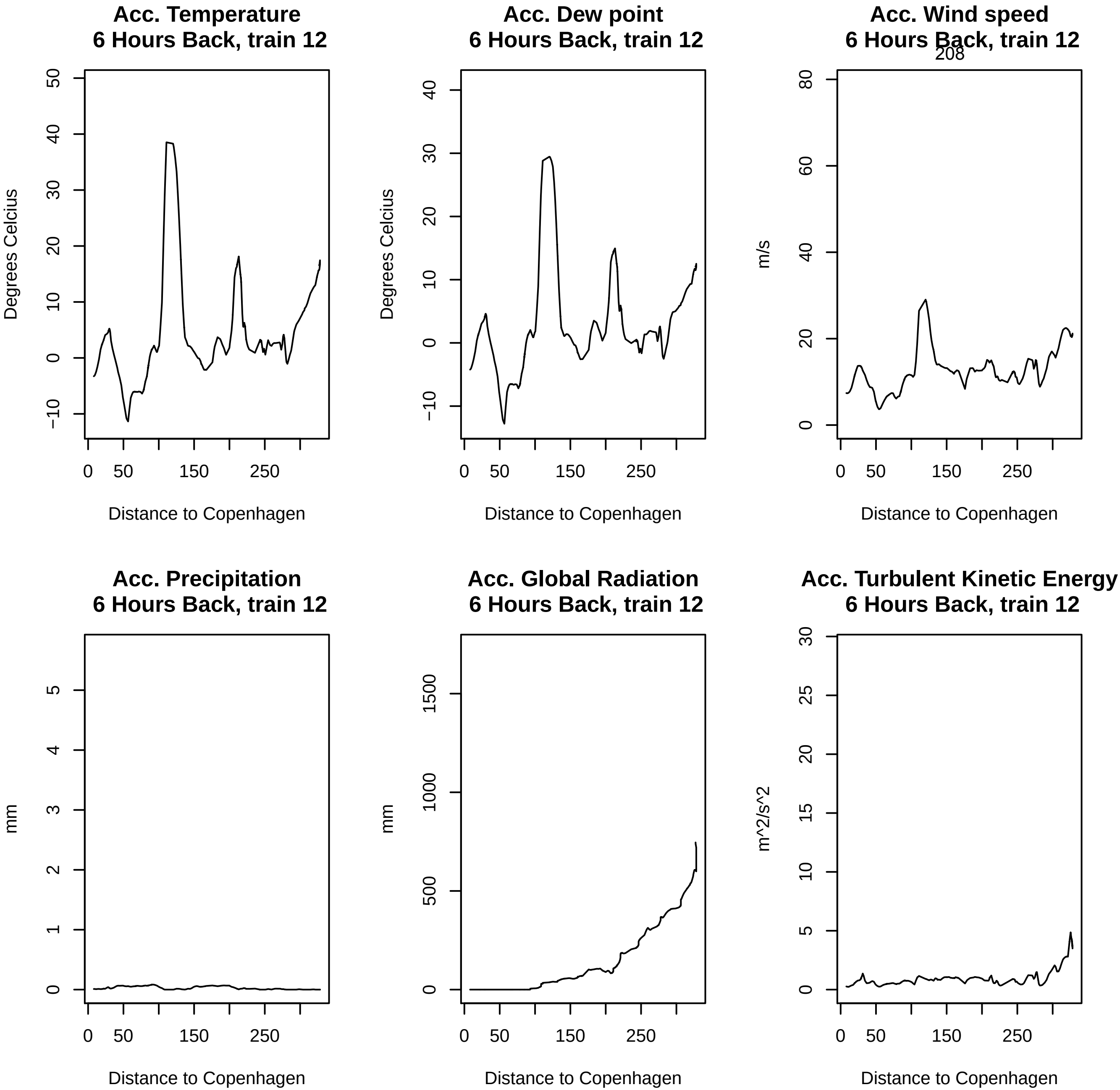

Acc. Temperature
24 Hours Back, train 11
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 11
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 11
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 11
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 11
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 11
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

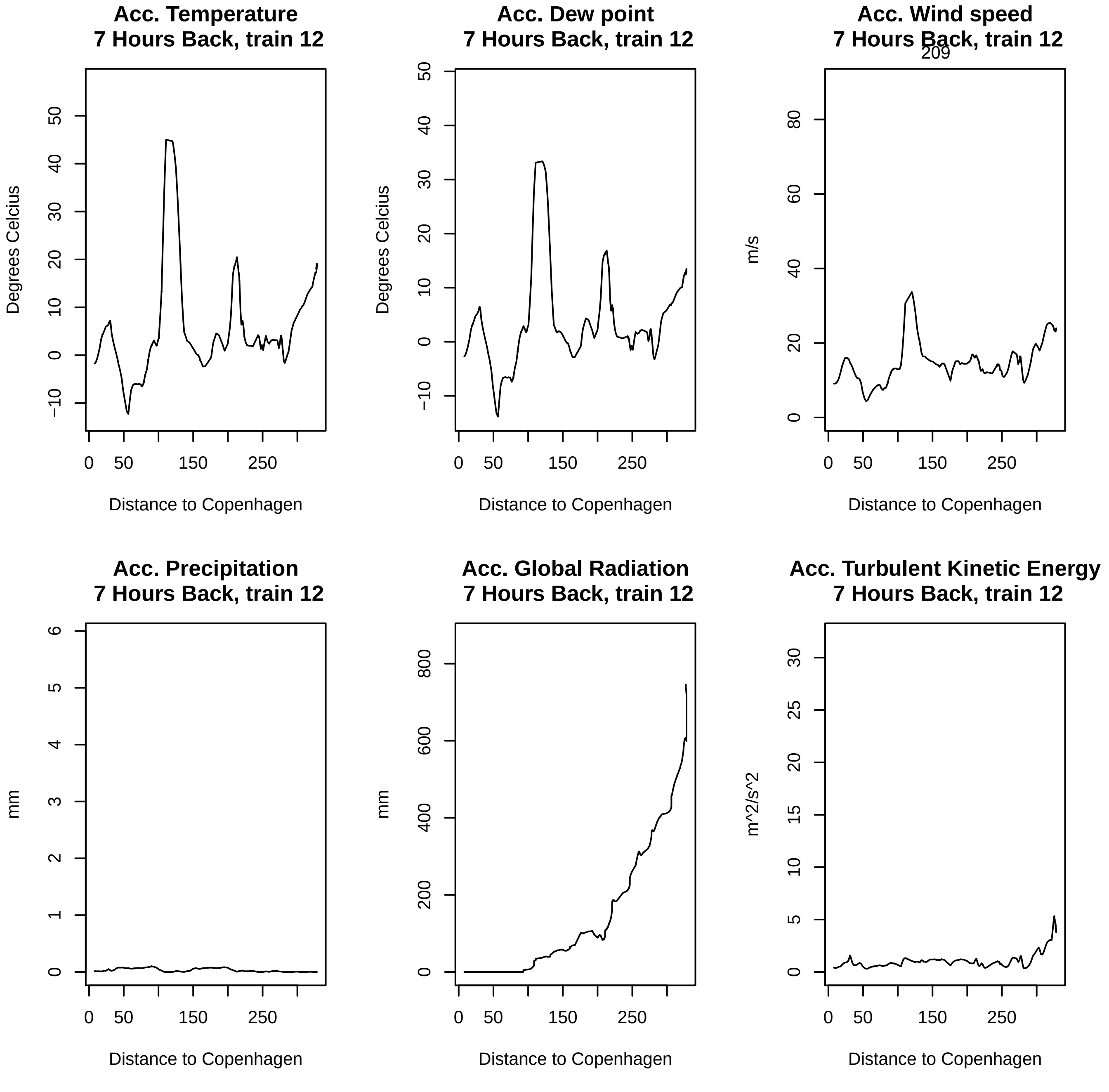

Temperature, train 12
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 12
Degrees Celcius
Distance to Copenhagen
Wind speed, train 12
m/s
0
5
10
15
Distance to Copenhagen
Precipitation, train 12
mm
0.0
0.5
1.0
1.5
Distance to Copenhagen
Global Radiation, train 12
mm
0
100
200
300
400
500
600
Distance to Copenhagen
Turbulent Kinetic Energy, train 12
m^2/s^2
0
1
2
3
4
5
Distance to Copenhagen

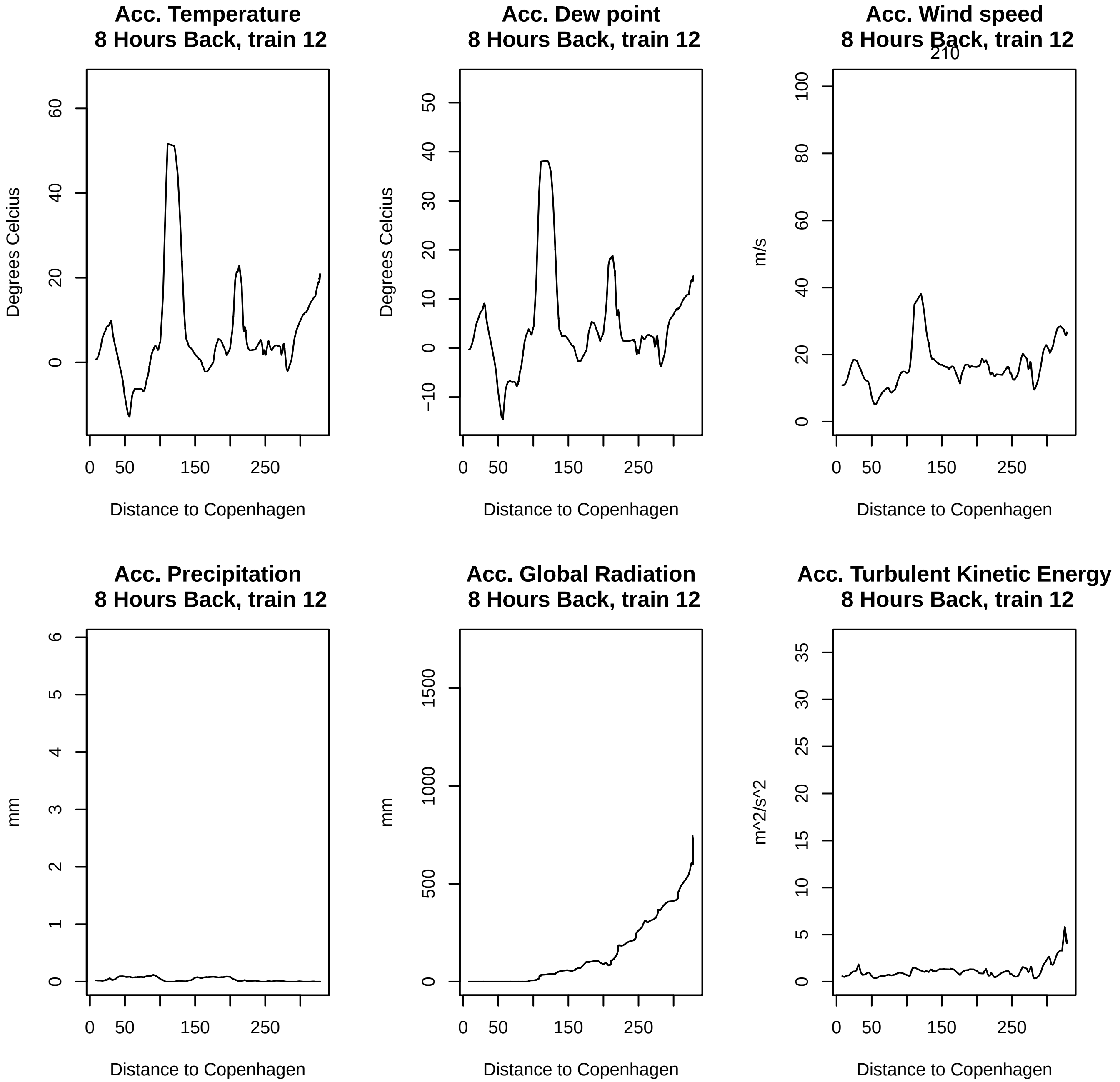

Acc. Temperature
3 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 12
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 12
m^2/s^2
Distance to Copenhagen

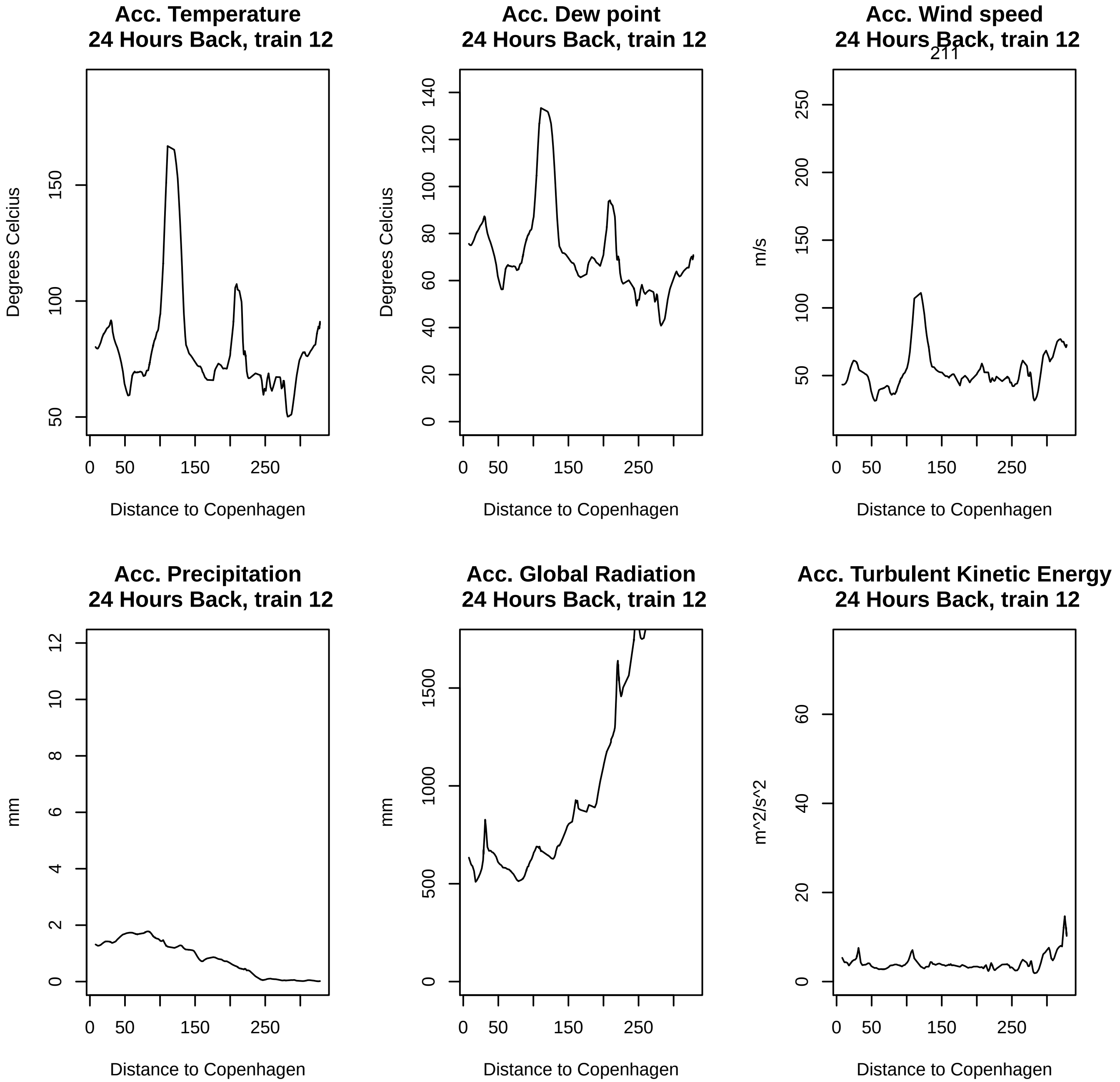

Acc. Temperature
5 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 12
m^2/s^2
Distance to Copenhagen

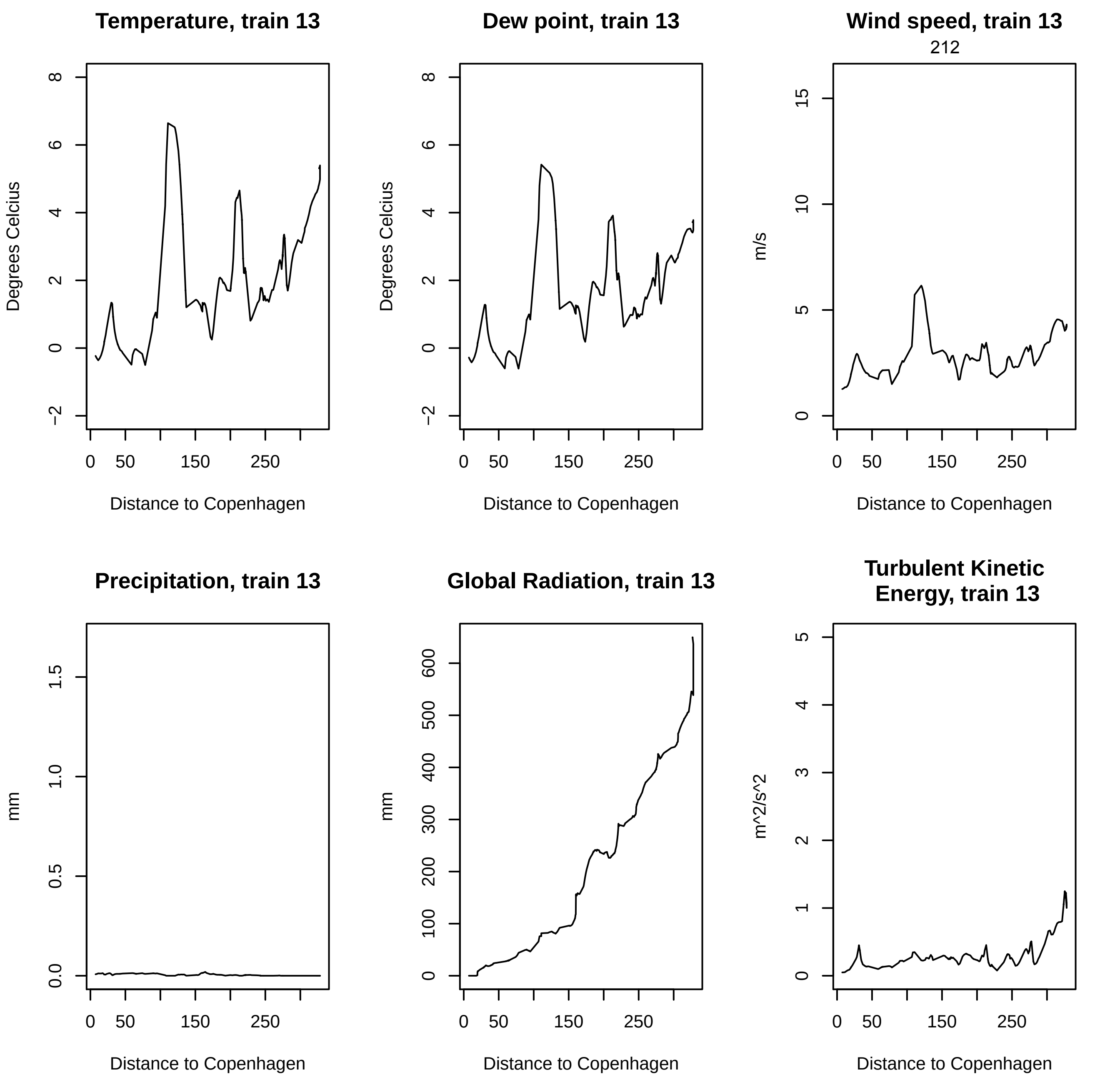

Acc. Temperature
6 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 12
m^2/s^2
Distance to Copenhagen

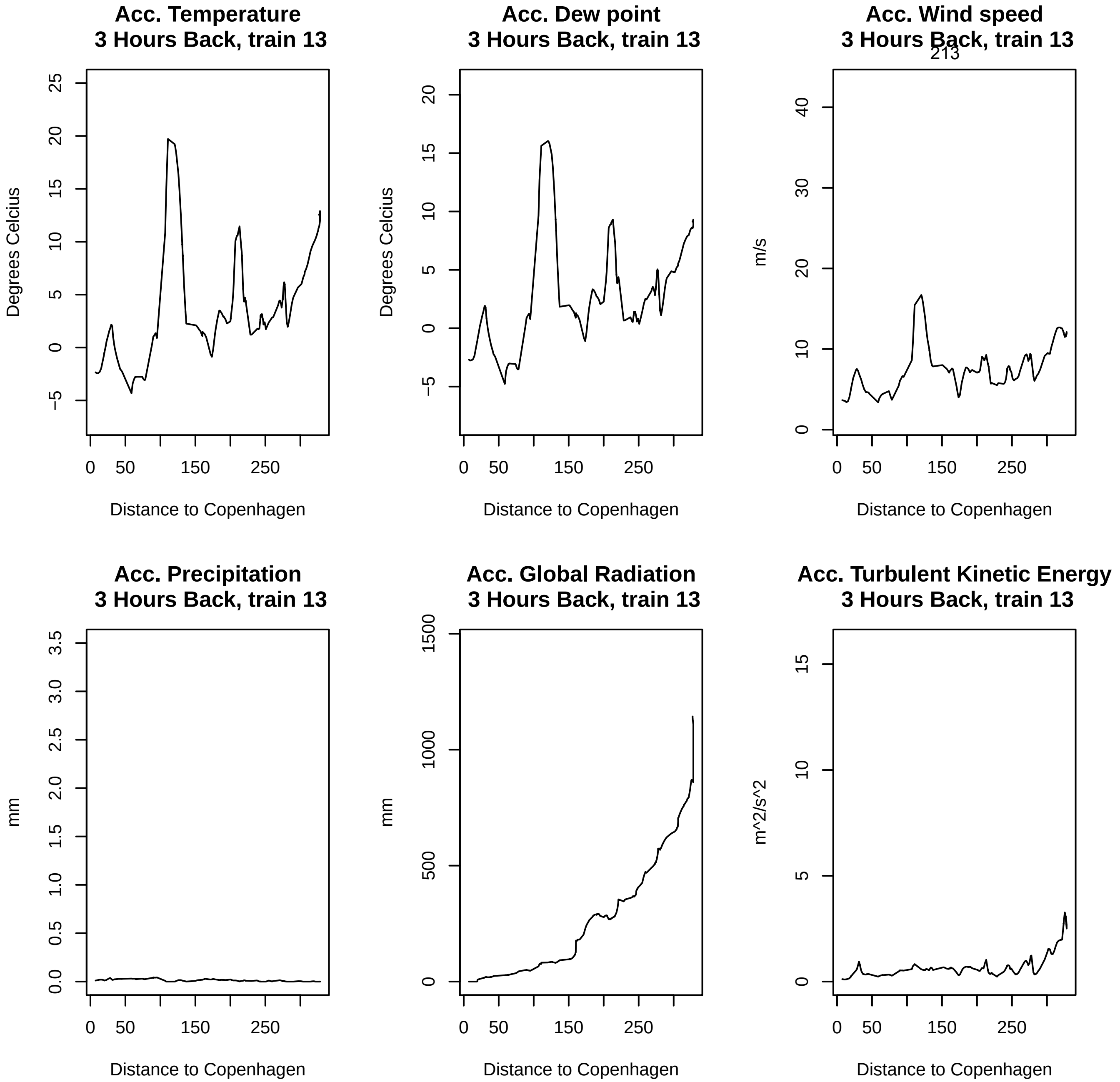

Acc. Temperature
7 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 12
m^2/s^2
Distance to Copenhagen

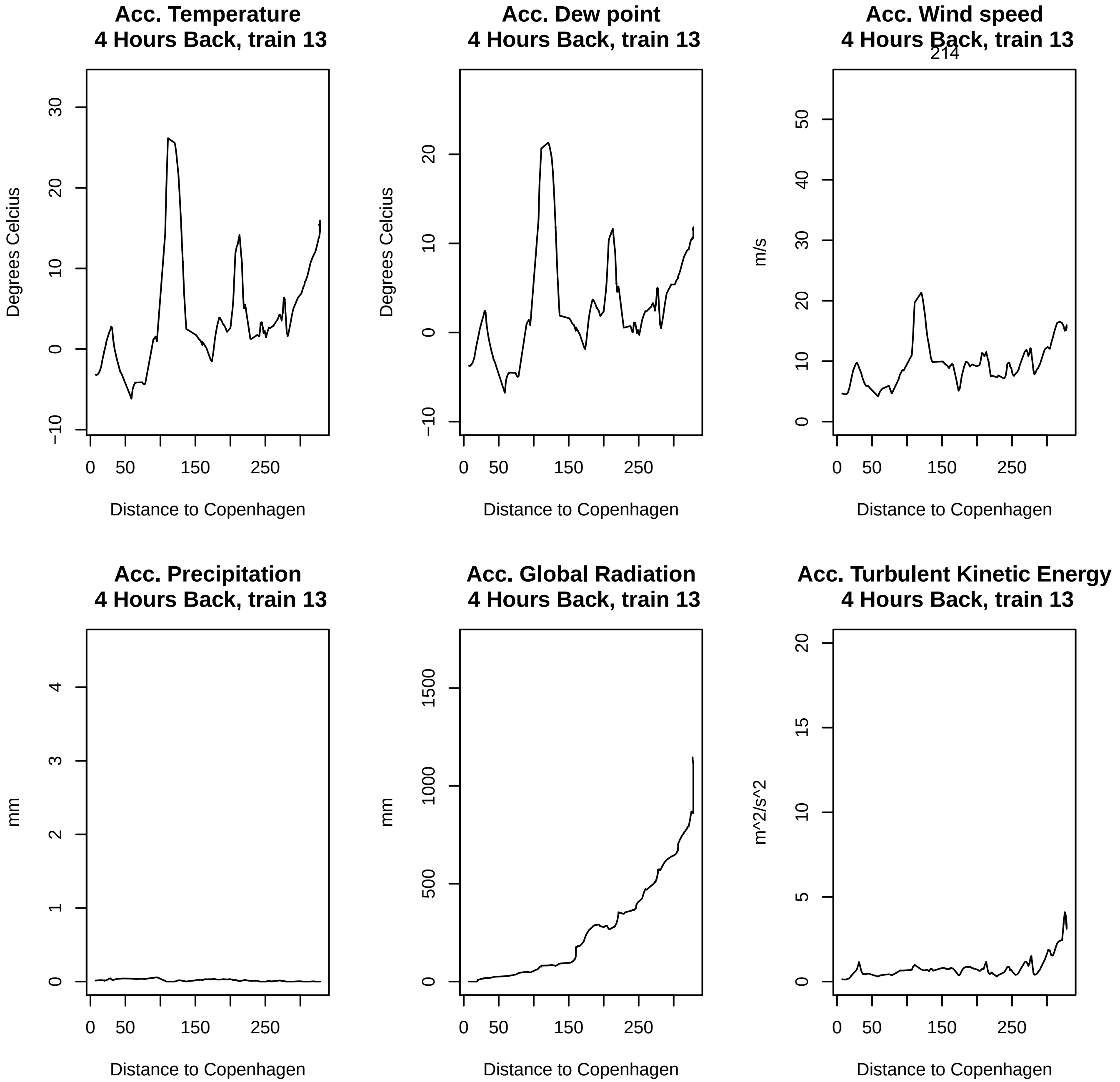


Acc. Temperature
8 Hours Back, train 12
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 12
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 12
210
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 12
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 12
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 12
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen

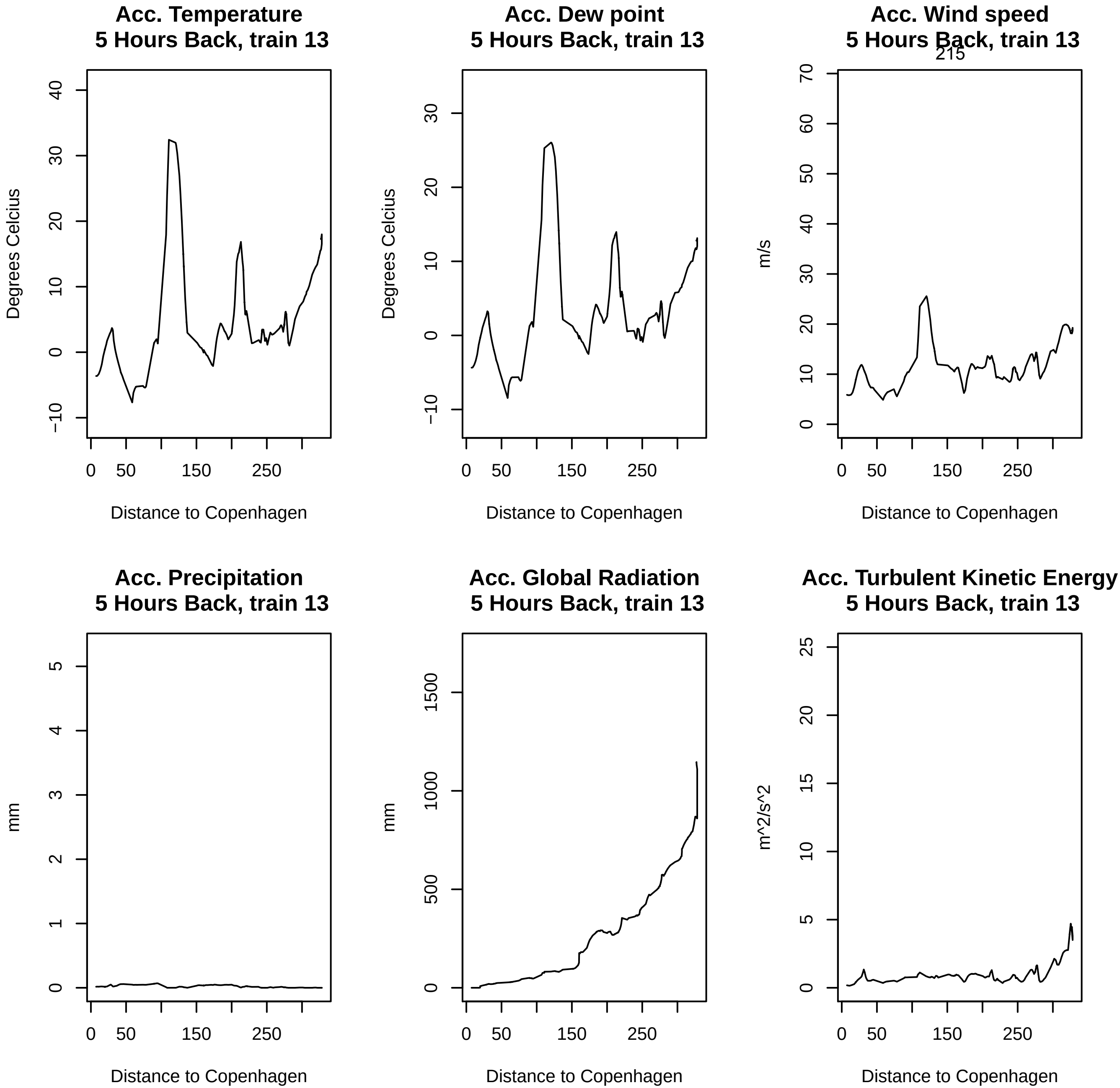

Acc. Temperature
24 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 12
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 12
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 12
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 12
m^2/s^2
Distance to Copenhagen

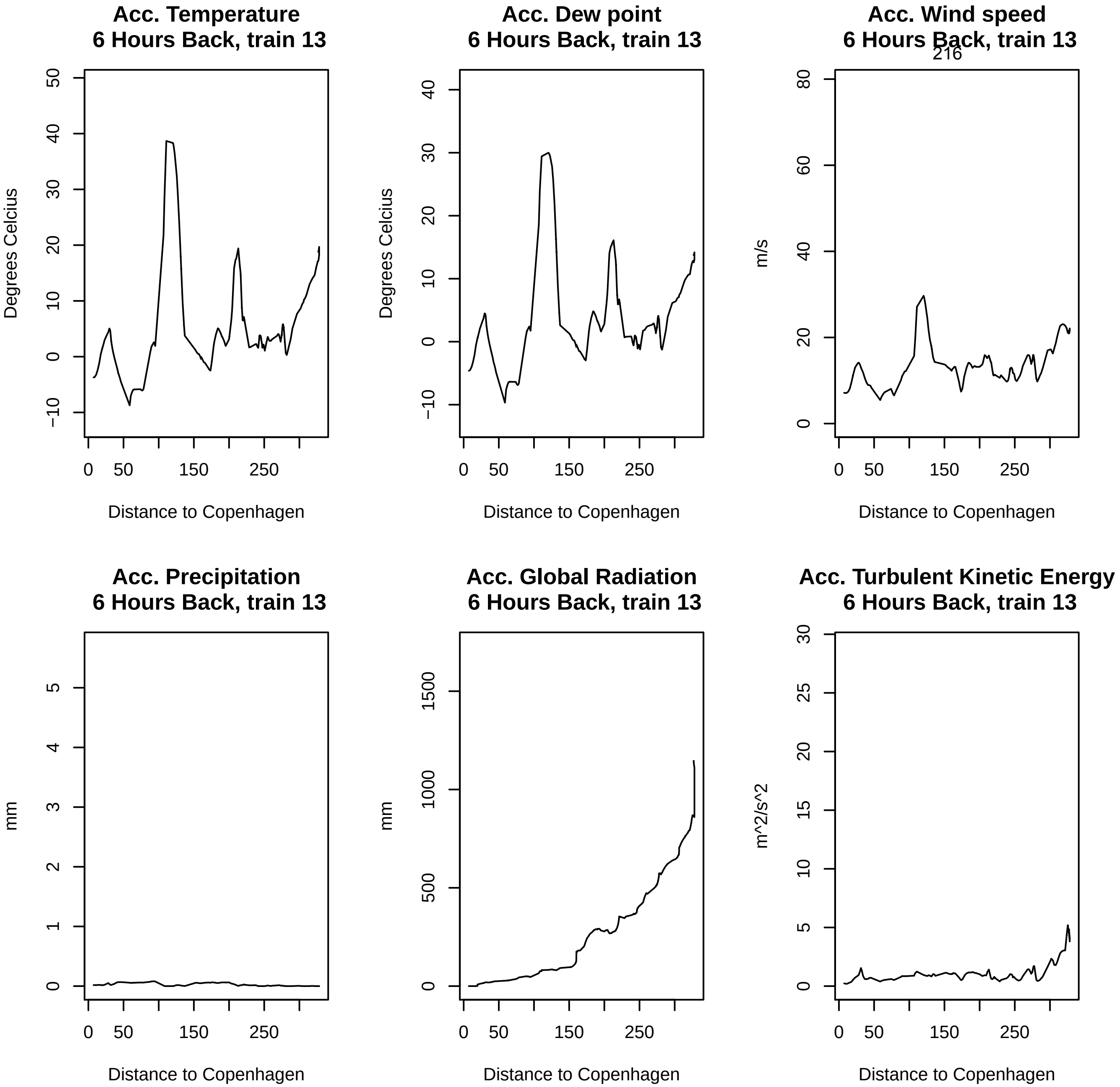

Temperature, train 13
Degrees Celcius
Dew point, train 13
Degrees Celcius
Wind speed, train 13
m/s
Precipitation, train 13
mm
Global Radiation, train 13
mm
Turbulent Kinetic Energy, train 13
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 13
Degrees Celcius
−5
0
5
10
15
20
25
Distance to Copenhagen
0
50
150
250
Acc. Dew point
3 Hours Back, train 13
Degrees Celcius
−5
0
5
10
15
20
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
3 Hours Back, train 13
m/s
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
3 Hours Back, train 13
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
3 Hours Back, train 13
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
3 Hours Back, train 13
m^2/s^2
0
5
10
15
Distance to Copenhagen
0
50
150
250

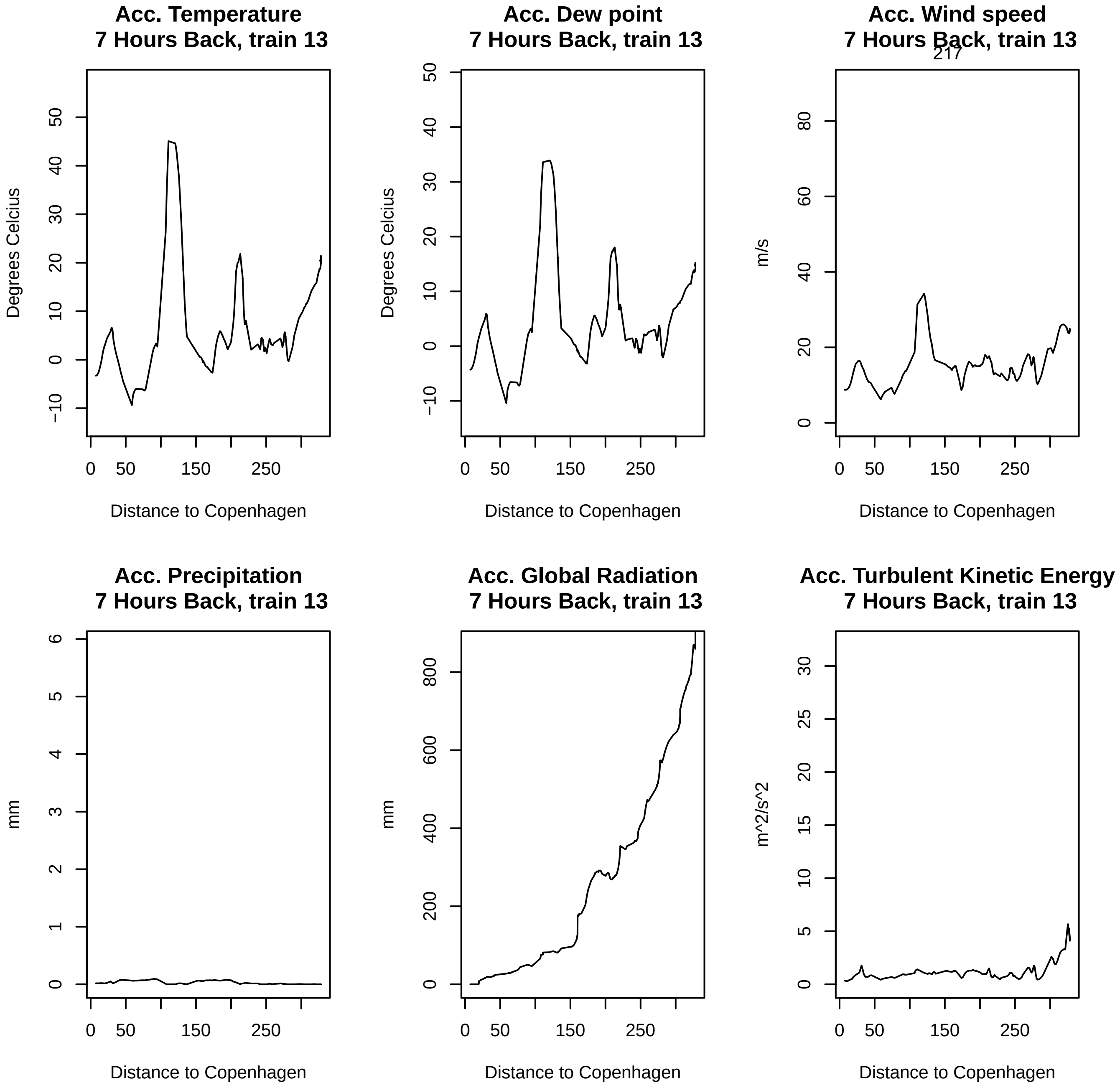


Acc. Temperature
4 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 13
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 13
m^2/s^2
Distance to Copenhagen
0
50
150
250

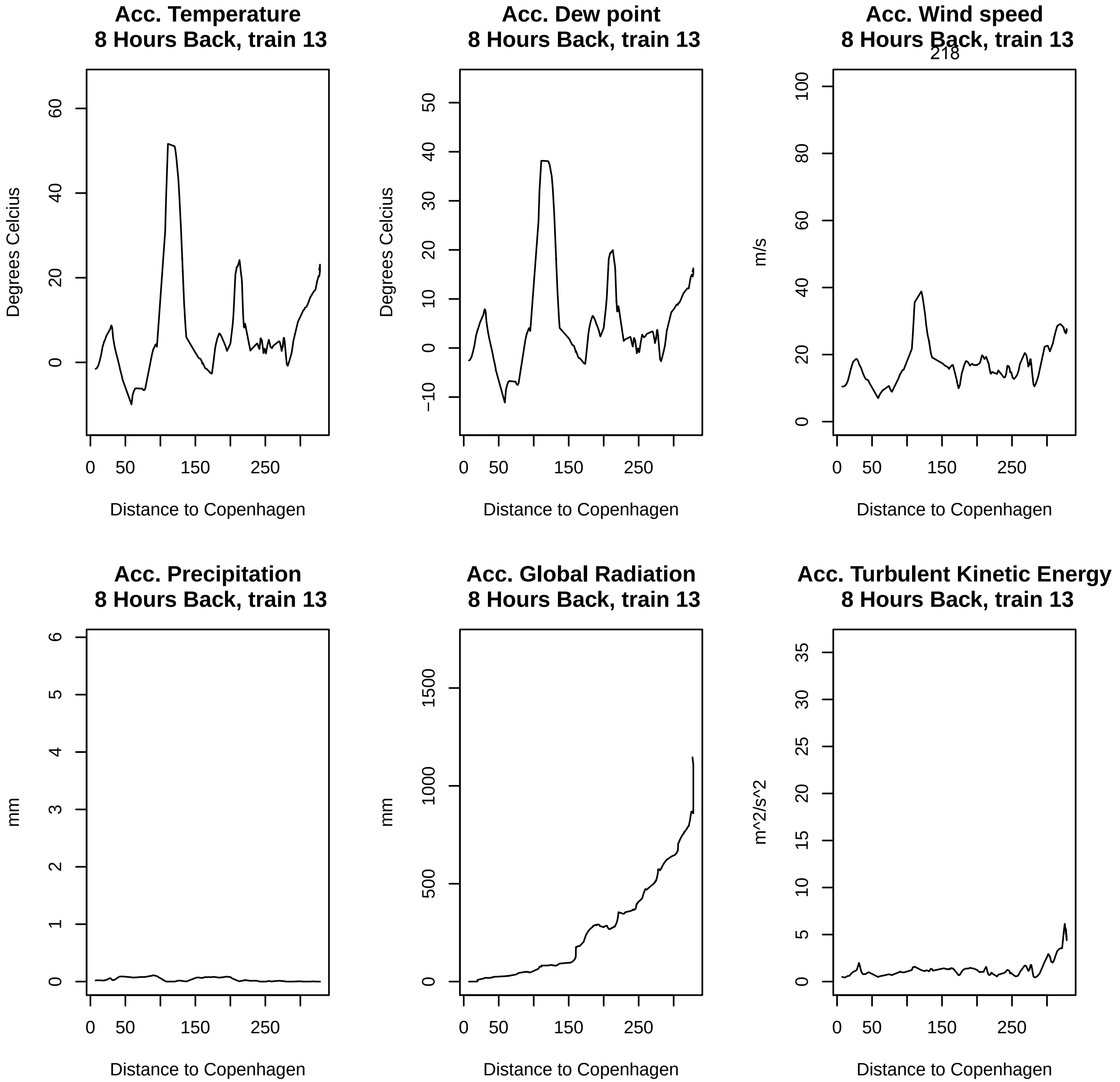

Acc. Temperature
5 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 13
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 13
m^2/s^2
Distance to Copenhagen

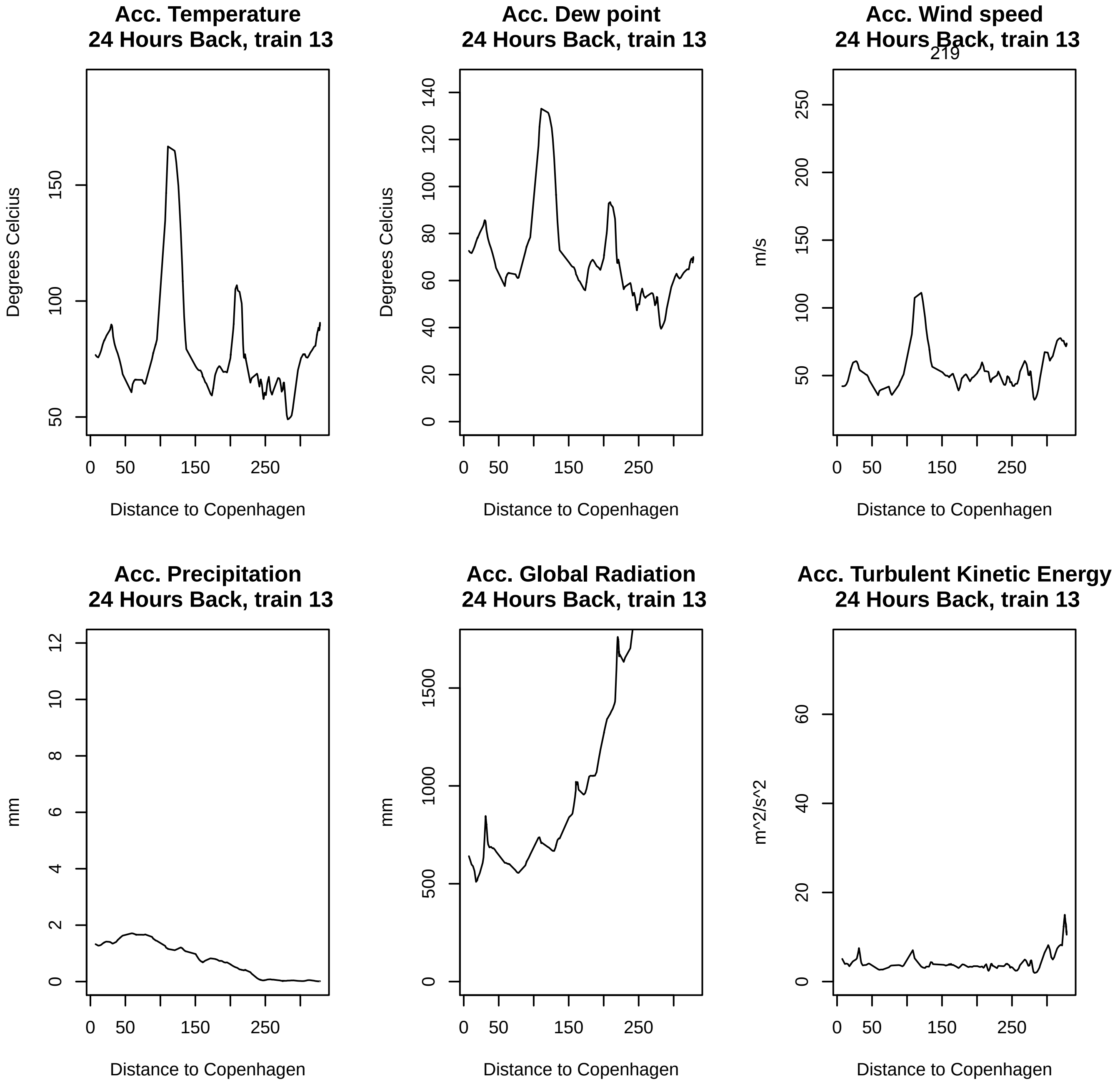


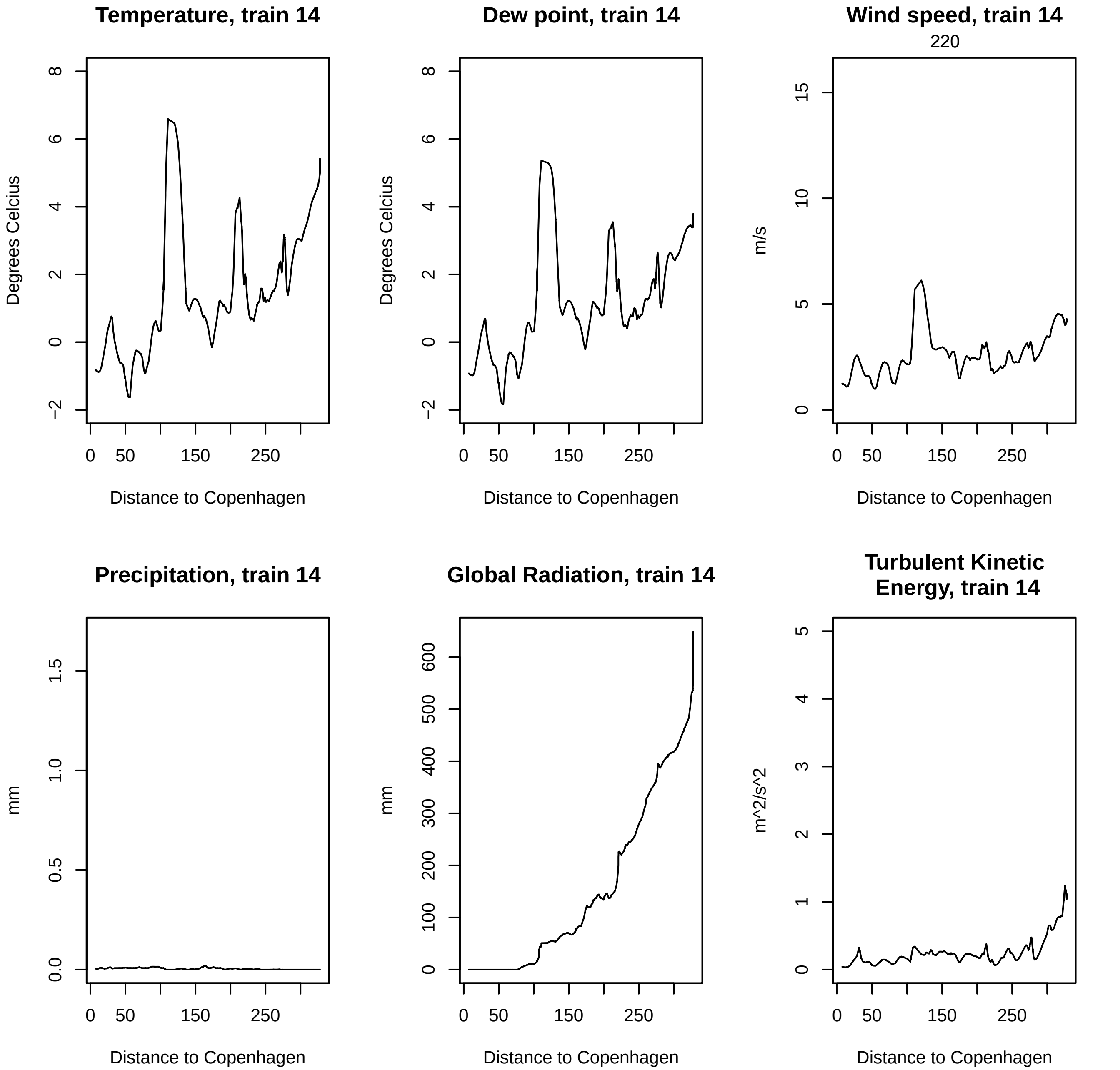
Acc. Temperature
6 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 13
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 13
m^2/s^2
Distance to Copenhagen

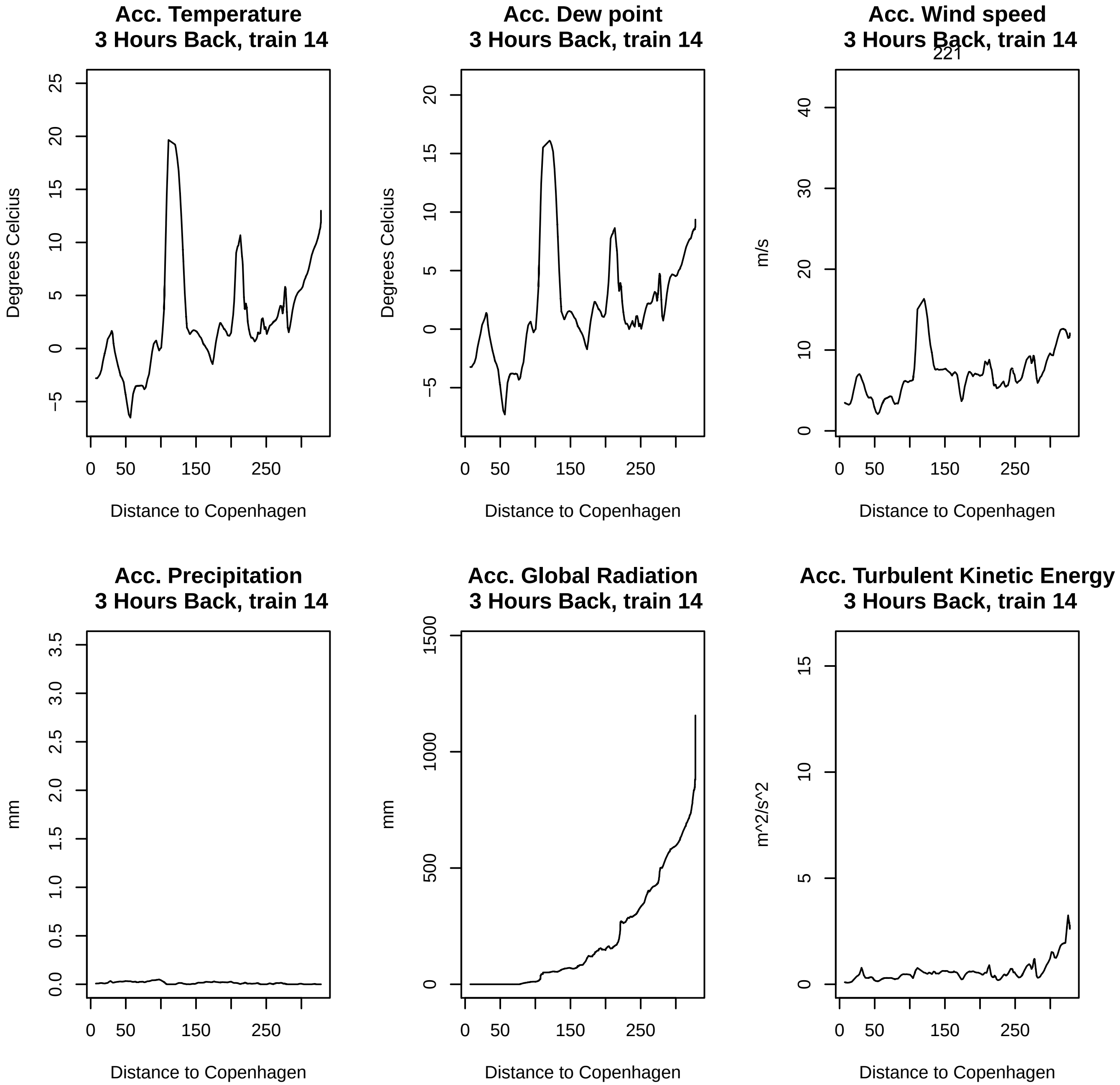


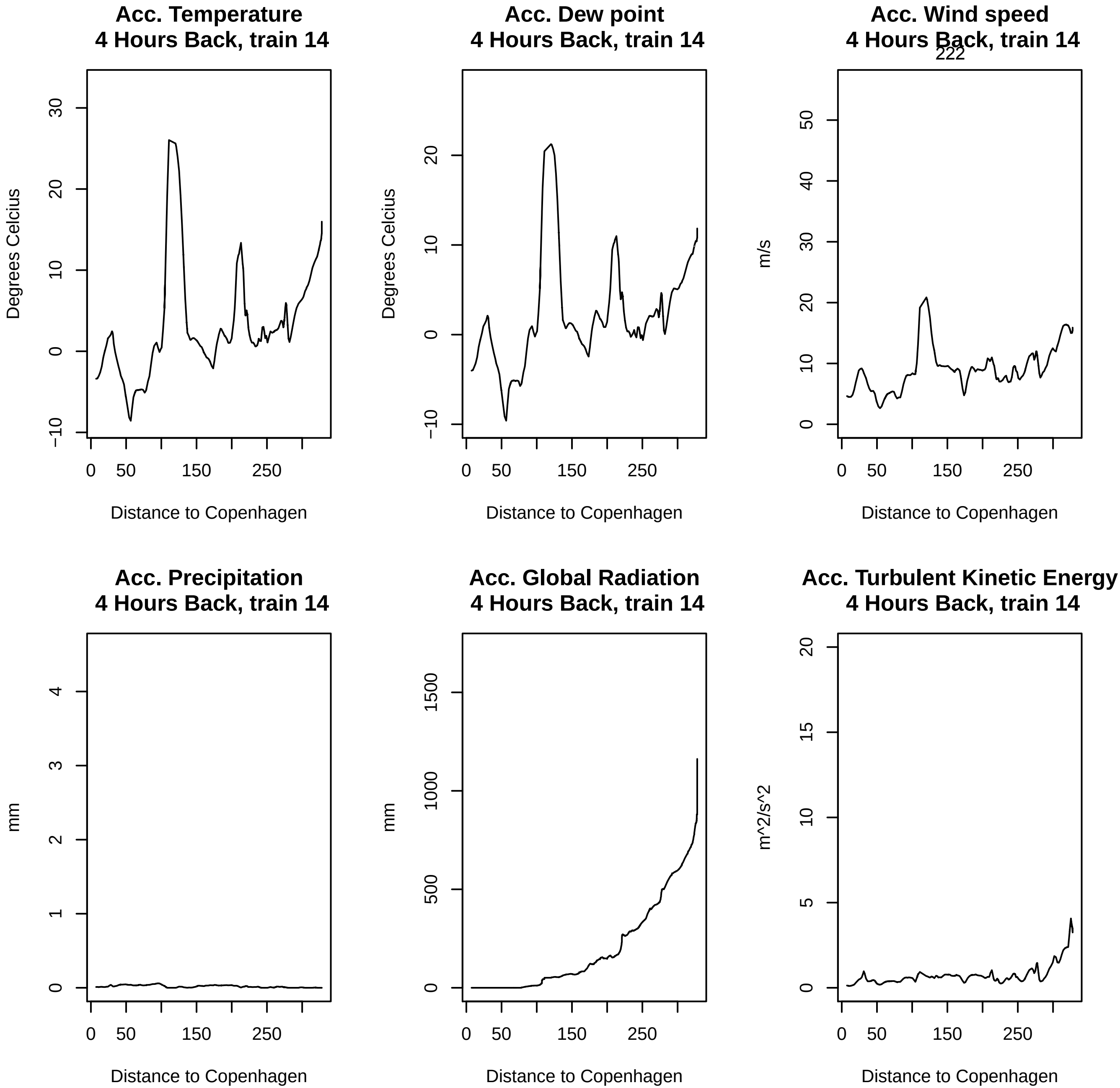
Acc. Temperature
7 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 13
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 13
217
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 13
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 13
m^2/s^2
Distance to Copenhagen

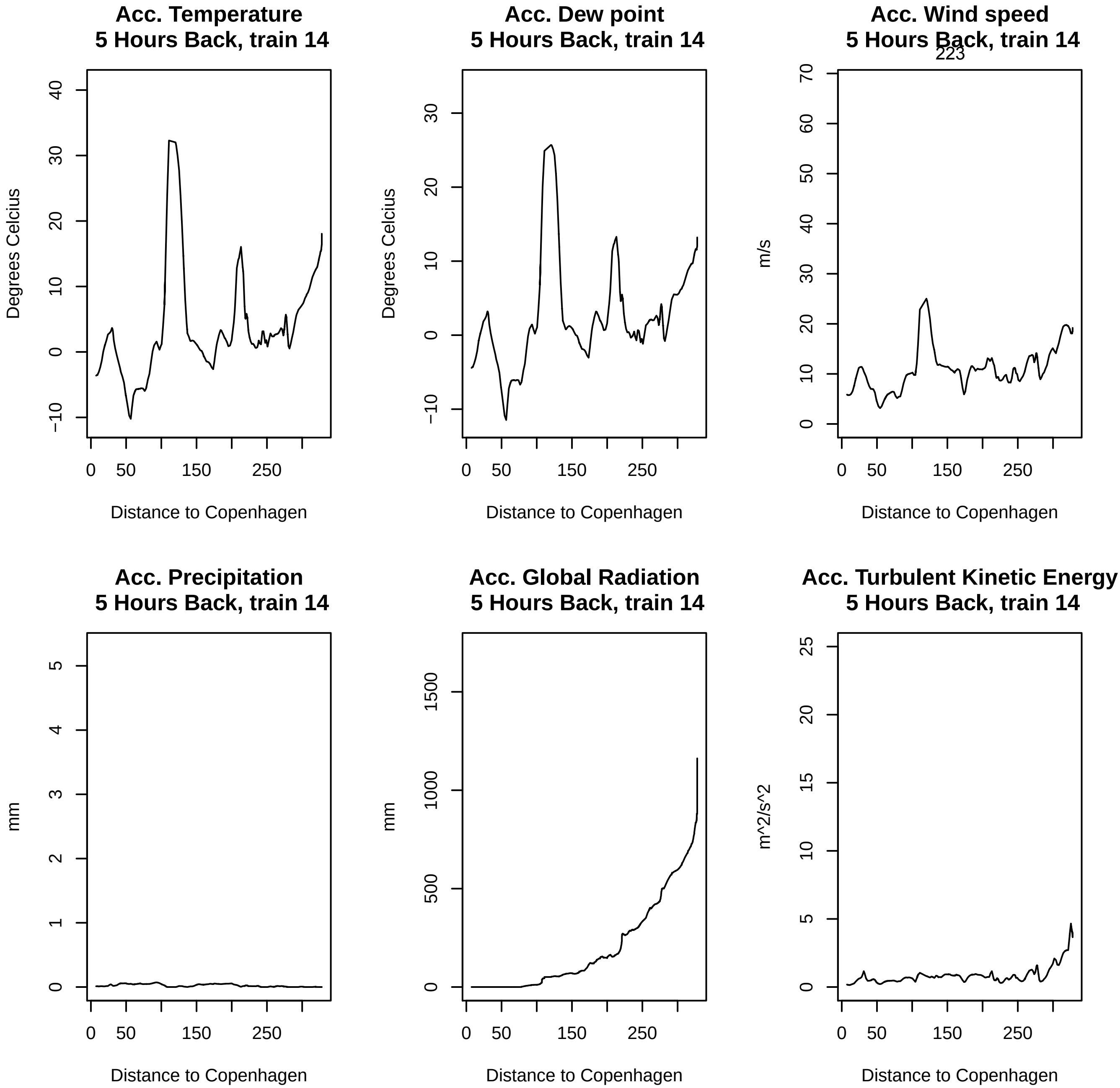

Acc. Temperature
8 Hours Back, train 13
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 13
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 13
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 13
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 13
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 13
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen

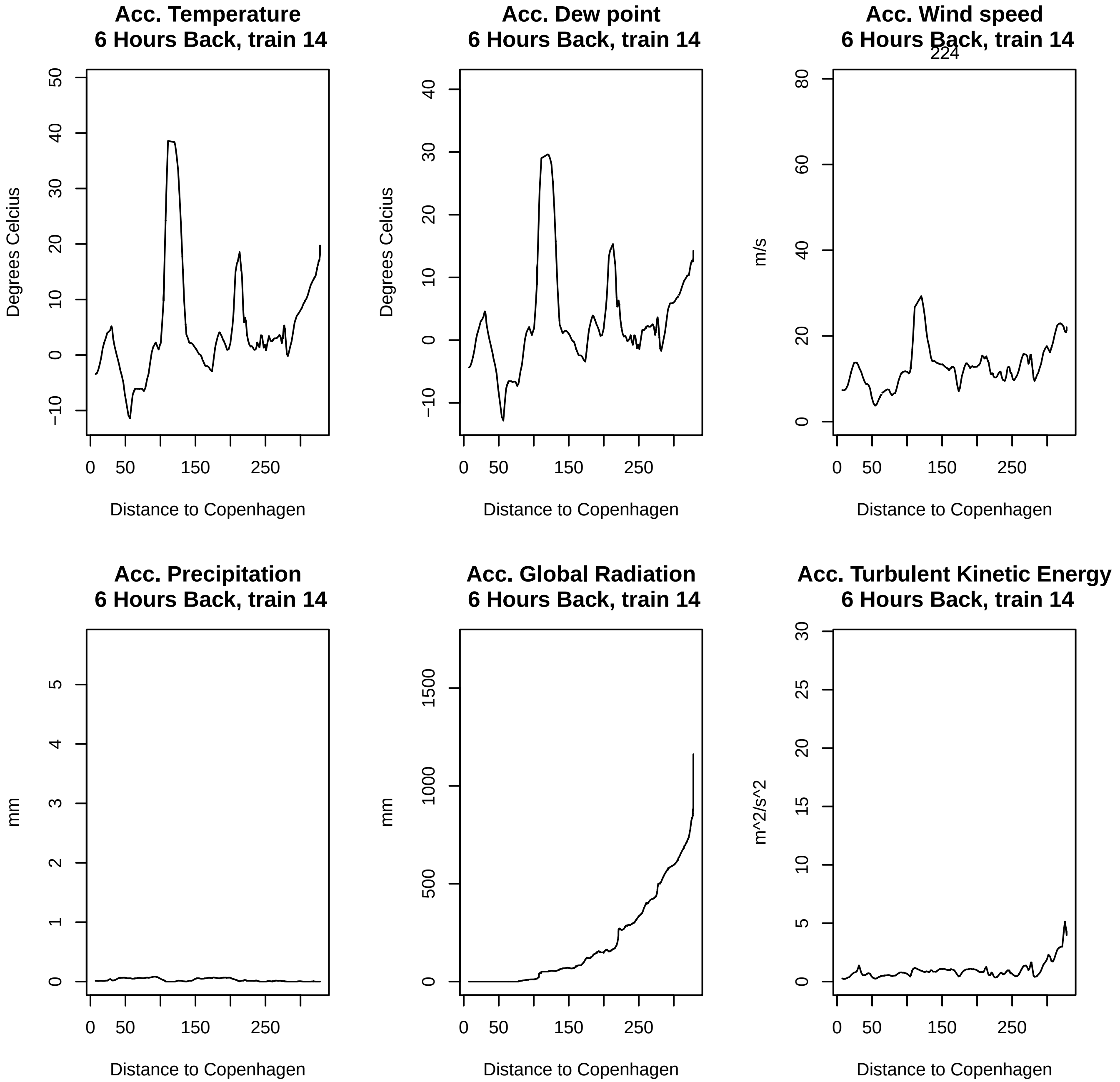

Acc. Temperature
24 Hours Back, train 13
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 13
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 13
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 13
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 13
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 13
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

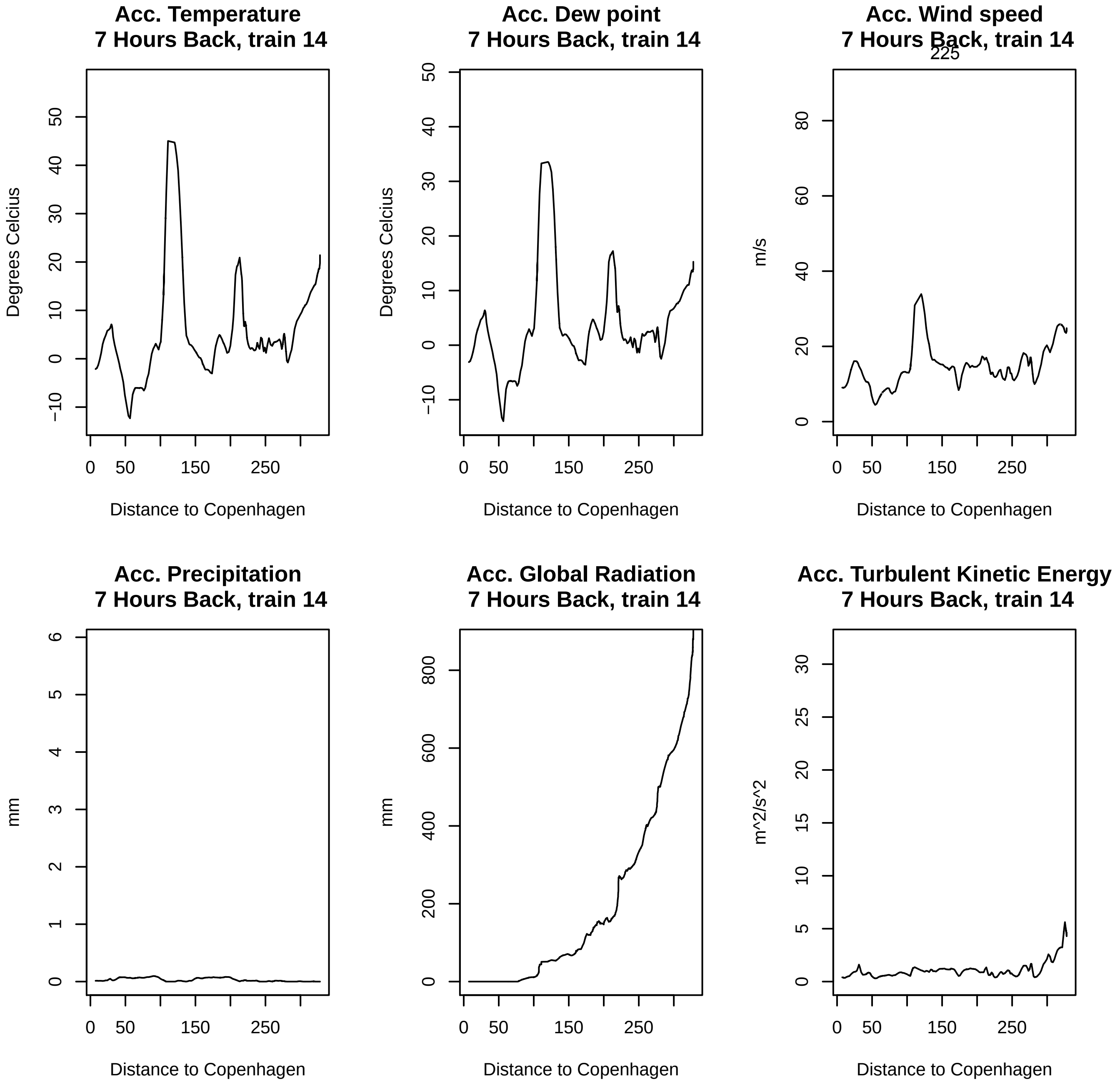

Temperature, train 14
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 14
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Wind speed, train 14
220
m/s
0
5
10
15
0
50
150
250
Distance to Copenhagen
Precipitation, train 14
mm
0.0
0.5
1.0
1.5
0
50
150
250
Distance to Copenhagen
Global Radiation, train 14
mm
0
100
200
300
400
500
600
0
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 14
m^2/s^2
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen

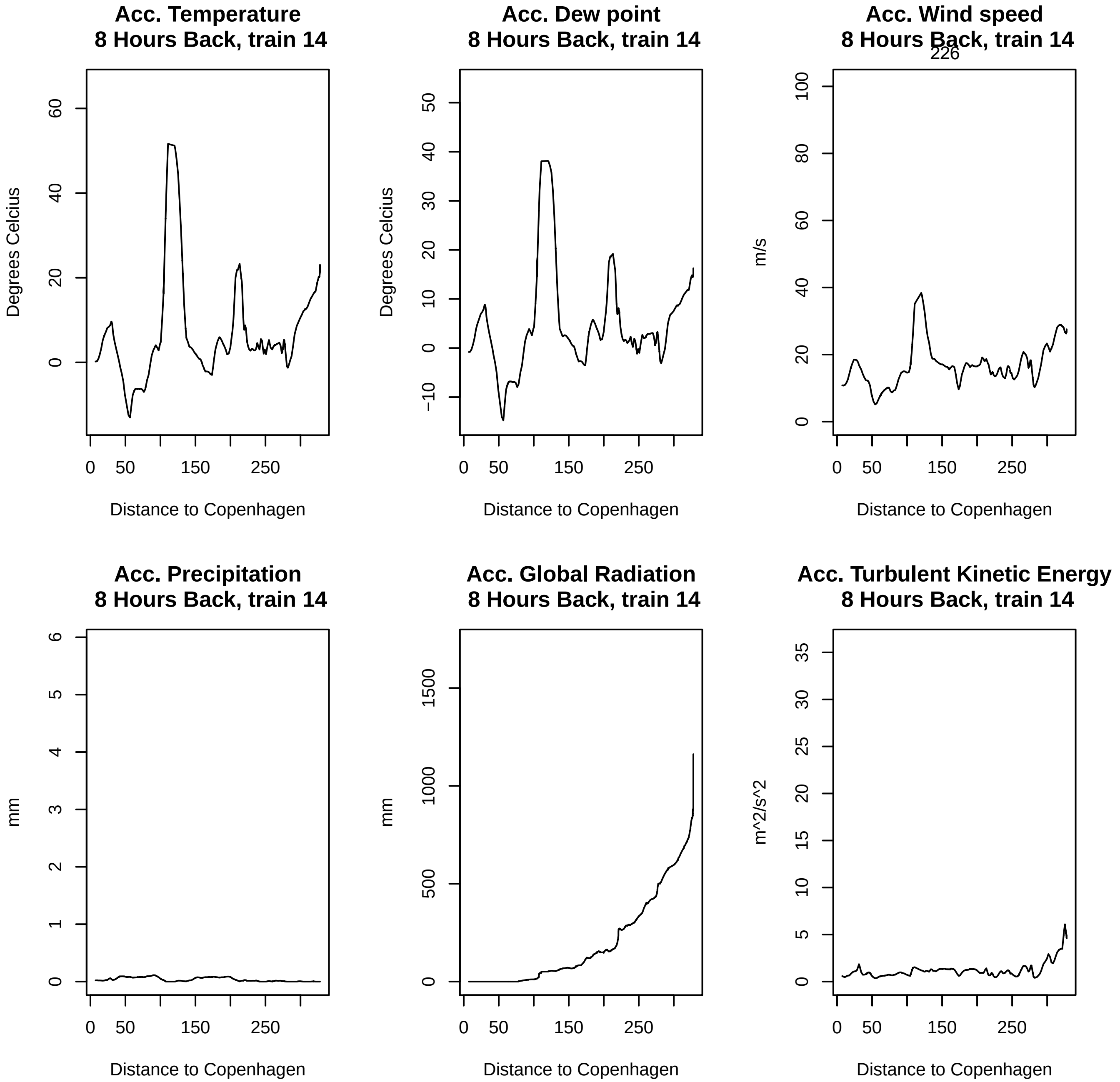

Acc. Temperature
3 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 14
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 14
m^2/s^2
Distance to Copenhagen

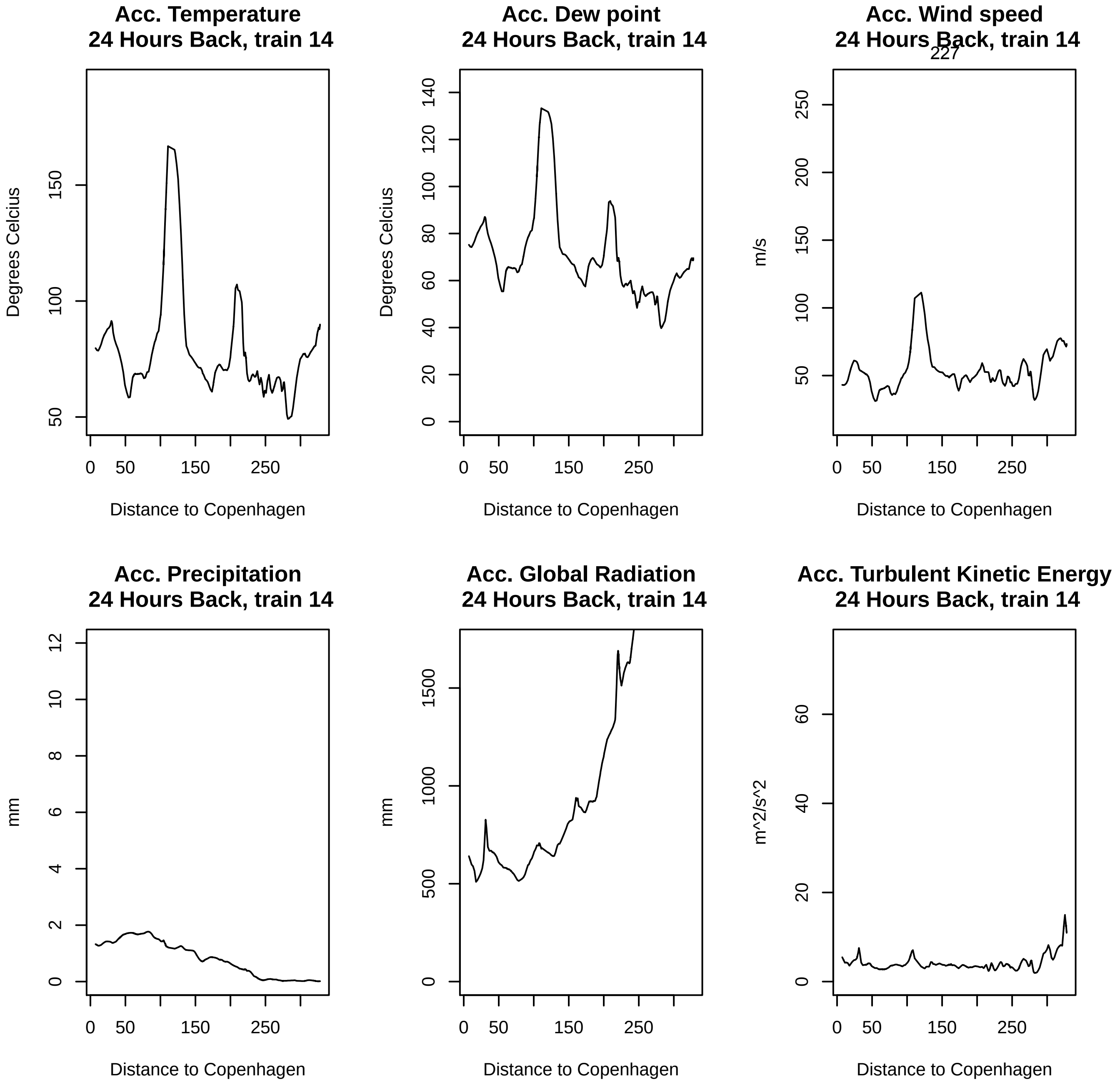

Acc. Temperature
4 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 14
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 14
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 14
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 14
m^2/s^2
Distance to Copenhagen

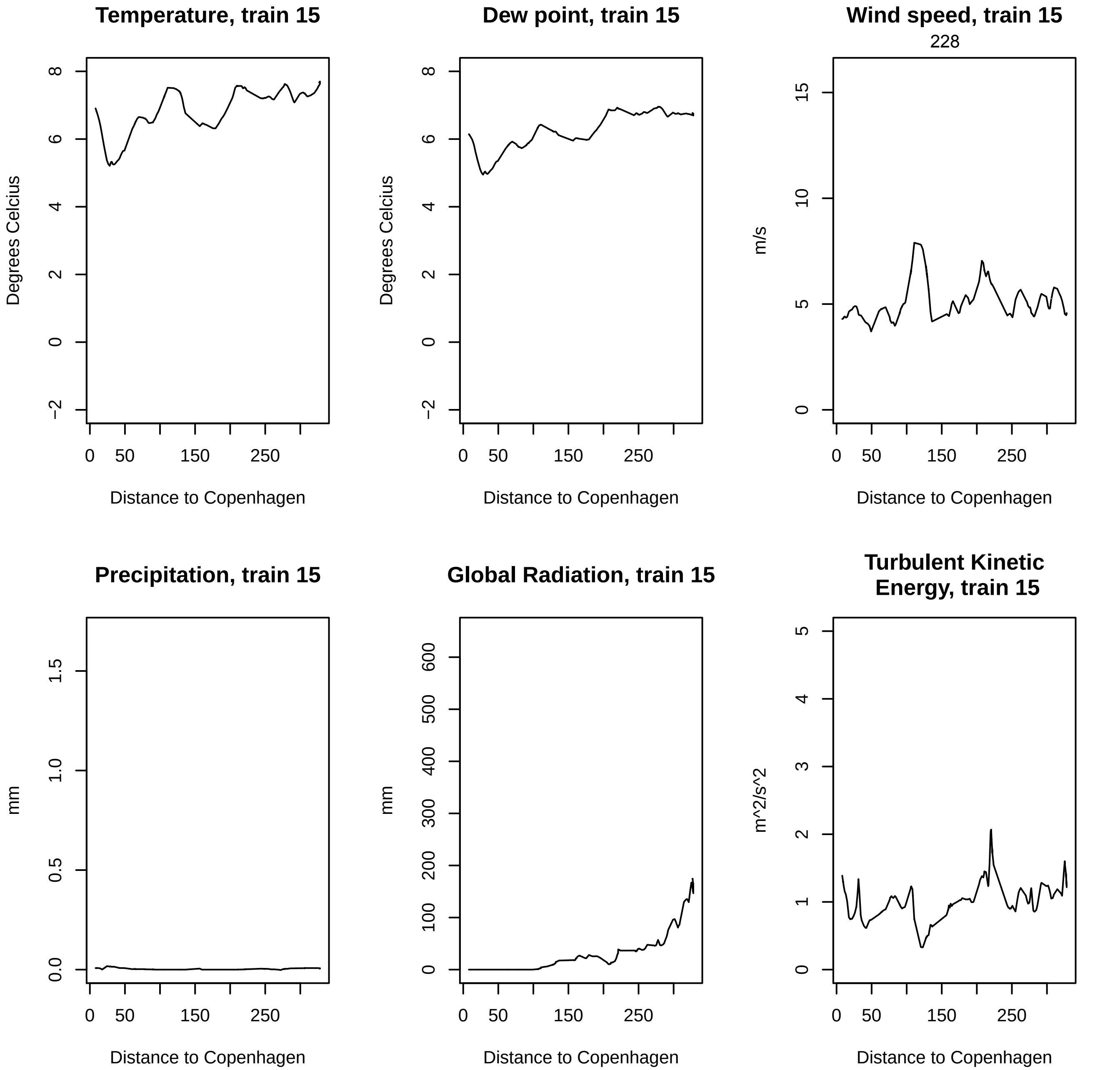

Acc. Temperature
6 Hours Back, train 14
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 14
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 14
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 14
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 14
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 14
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

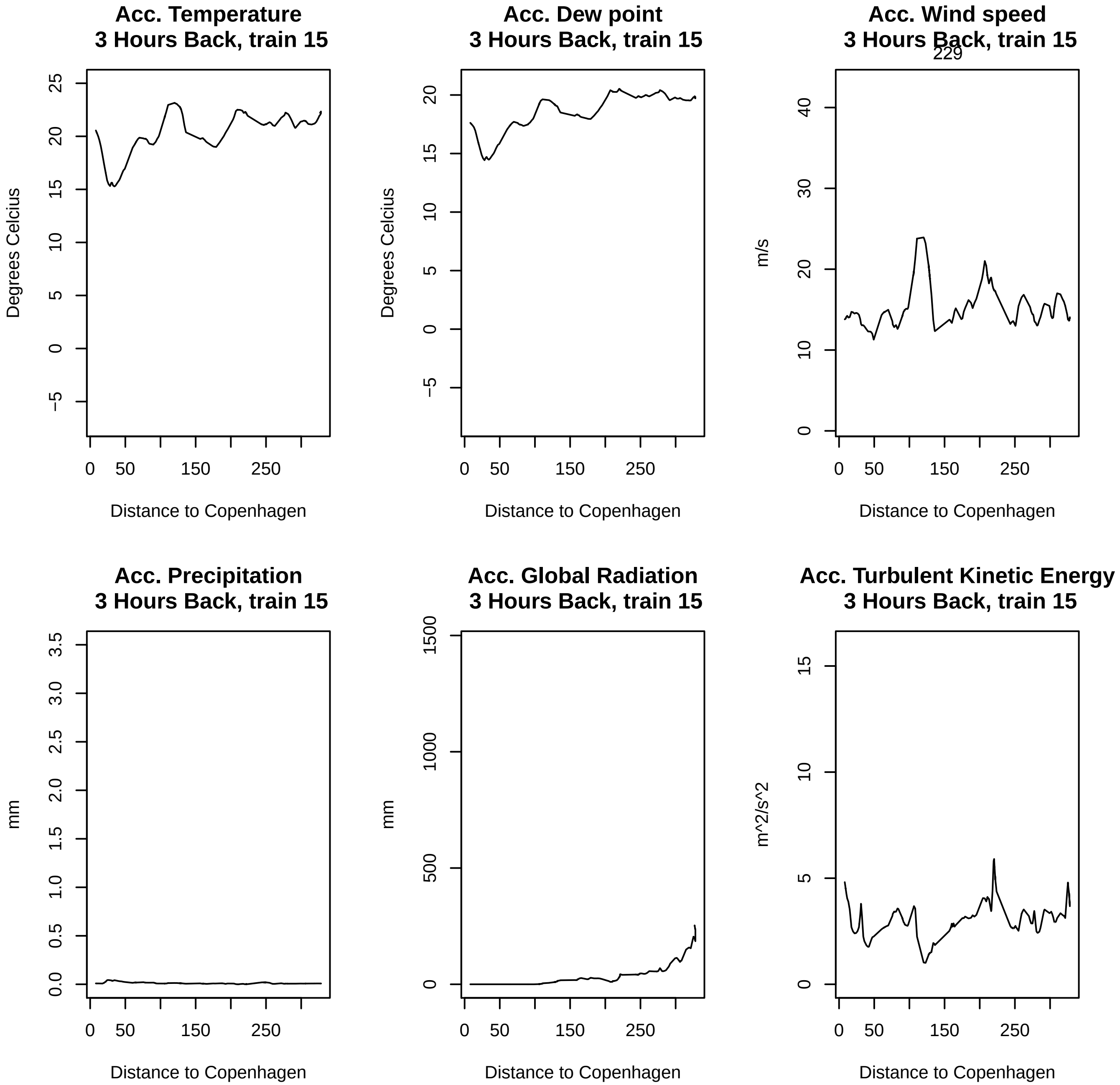

Acc. Temperature
7 Hours Back, train 14
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 14
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 14
225
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 14
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 14
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 14
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 14
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 14
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 14
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 14
m^2/s^2
Distance to Copenhagen



Acc. Temperature
24 Hours Back, train 14
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 14
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 14
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 14
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 14
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 14
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen


Temperature, train 15
Degrees Celcius
−2
0
2
4
6
8
Distance to Copenhagen
0
50
150
250
Dew point, train 15
Degrees Celcius
−2
0
2
4
6
8
Distance to Copenhagen
0
50
150
250
Wind speed, train 15
228
m/s
0
5
10
15
Distance to Copenhagen
0
50
150
250
Precipitation, train 15
mm
0.0
0.5
1.0
1.5
Distance to Copenhagen
0
50
150
250
Global Radiation, train 15
mm
0
100
200
300
400
500
600
Distance to Copenhagen
0
50
150
250
Turbulent Kinetic Energy, train 15
m^2/s^2
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250



Acc. Temperature
3 Hours Back, train 15
Degrees Celcius
−5
0
5
10
15
20
25
0
50
150
250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 15
Degrees Celcius
−5
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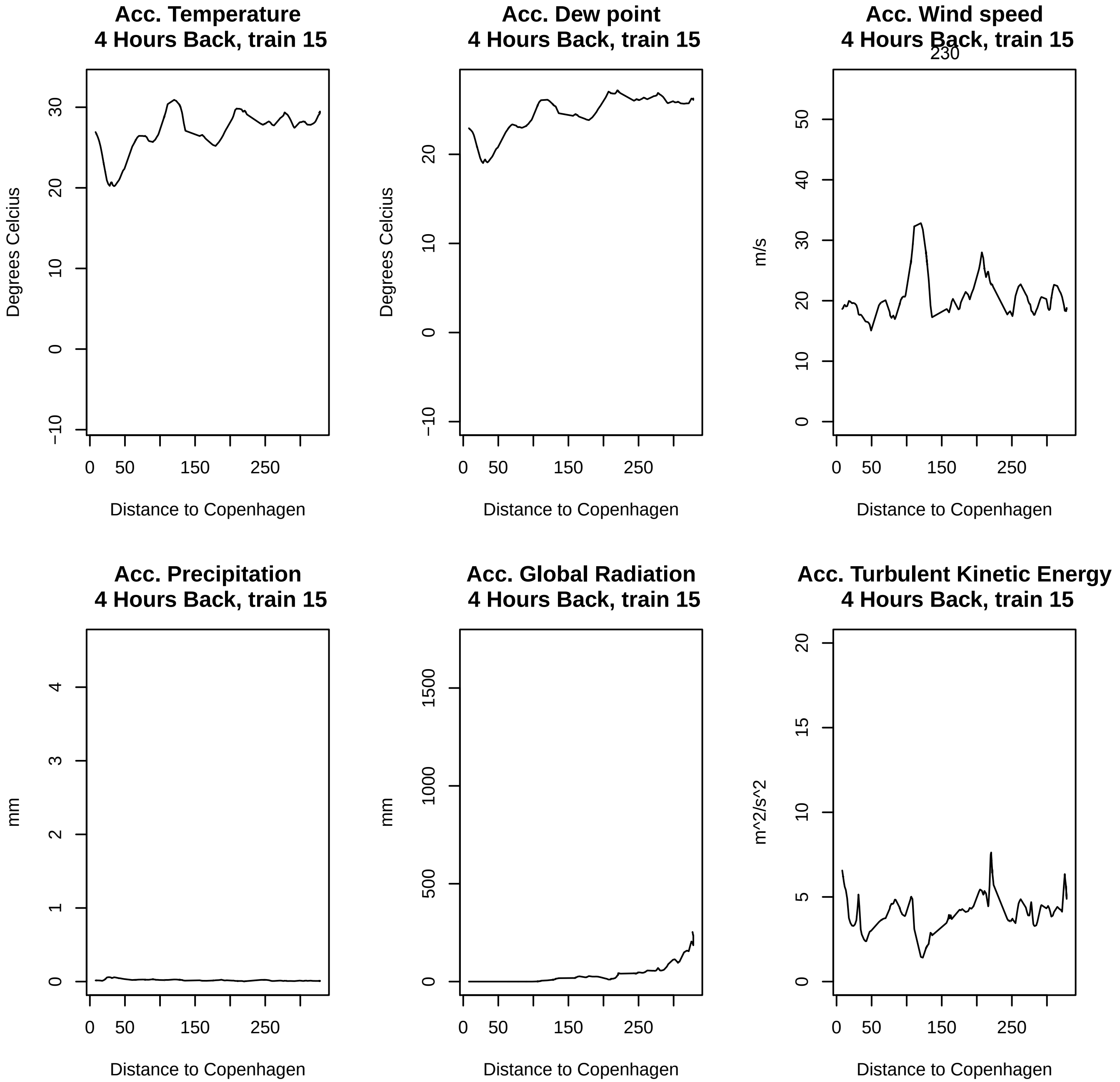
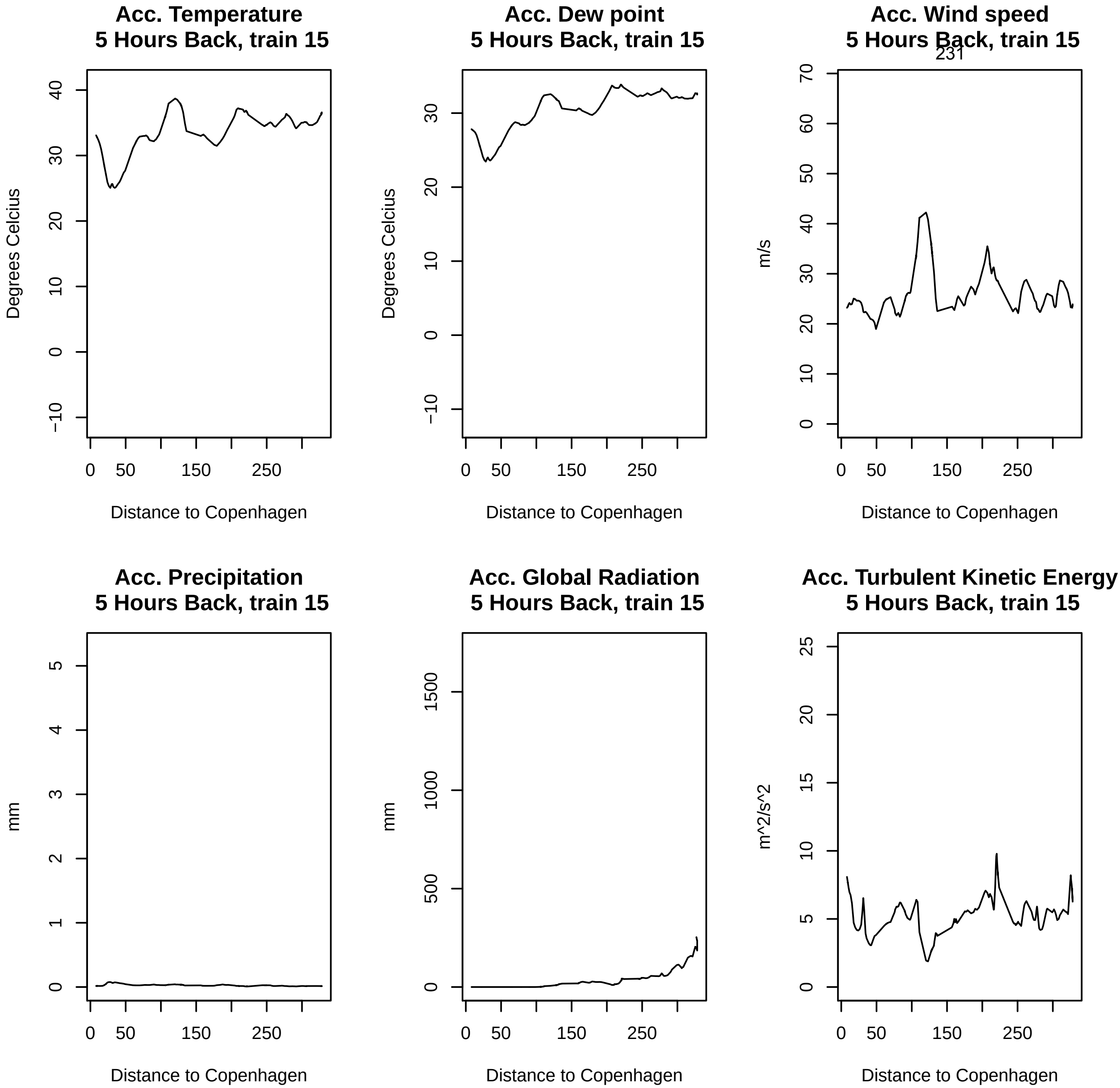
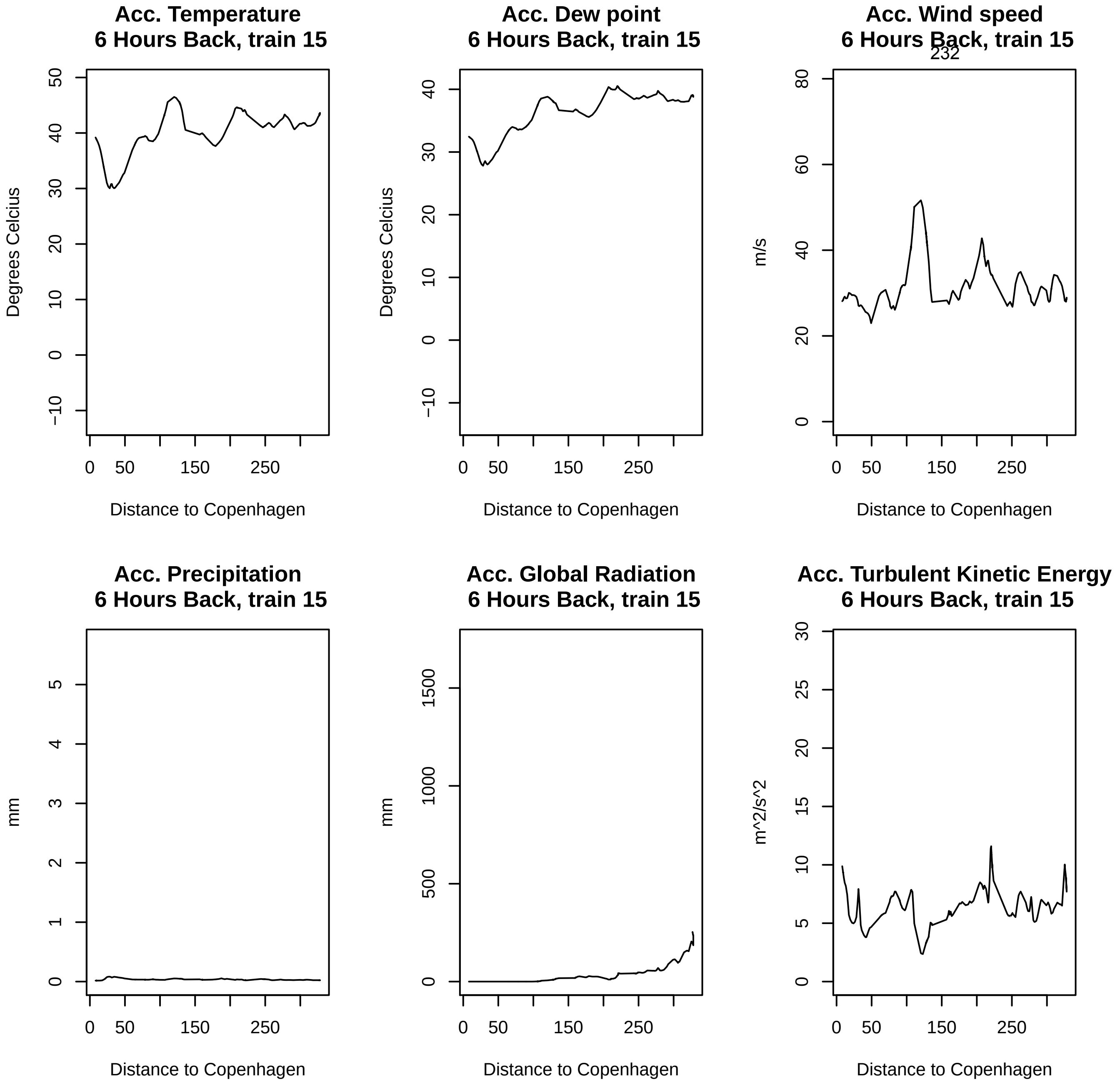
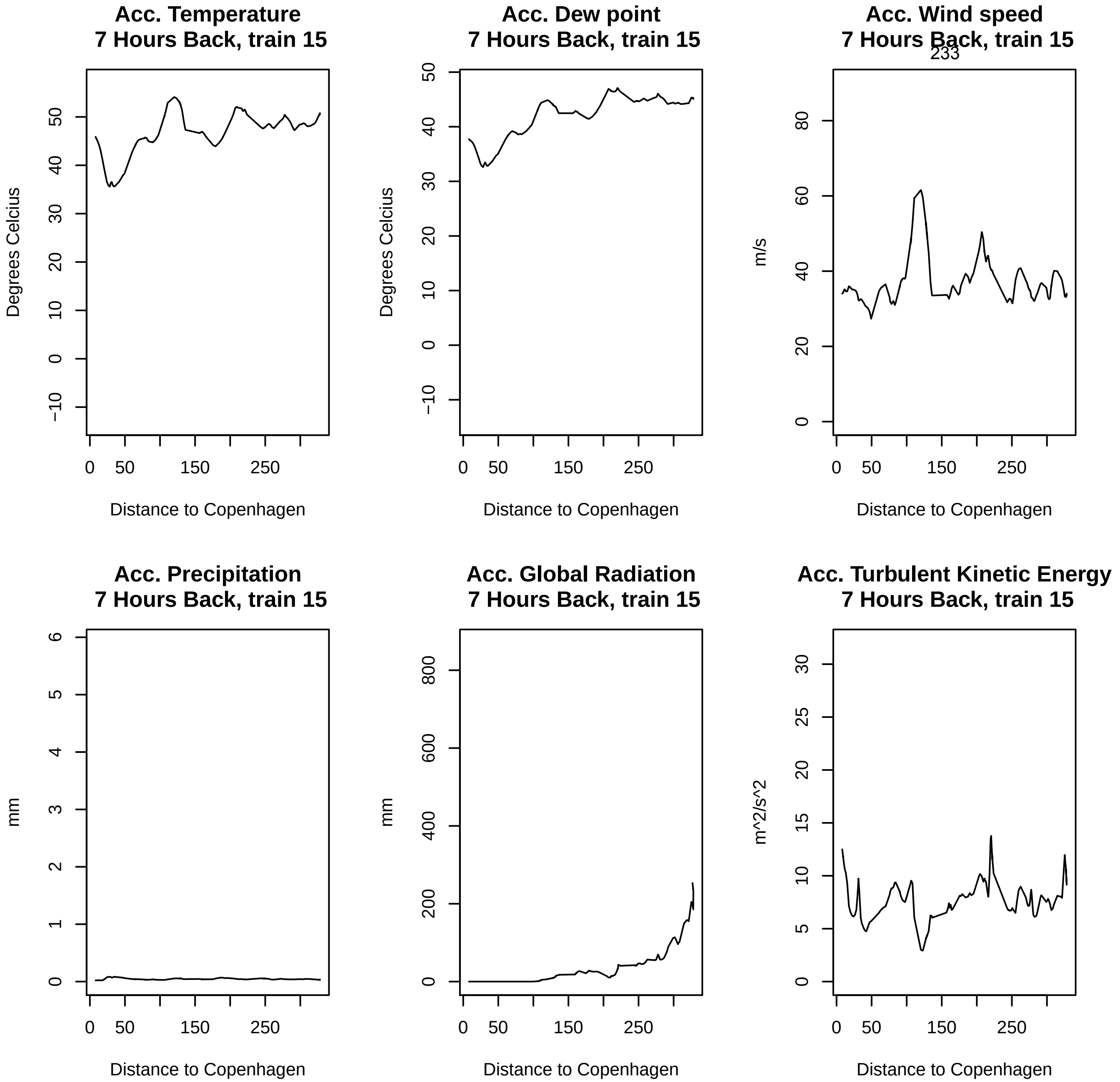
5
10
15
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 15
229
m/s
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 15
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 15
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 15
m^2/s^2
0
5
10
15
0
50
150
250
Distance to Copenhagen

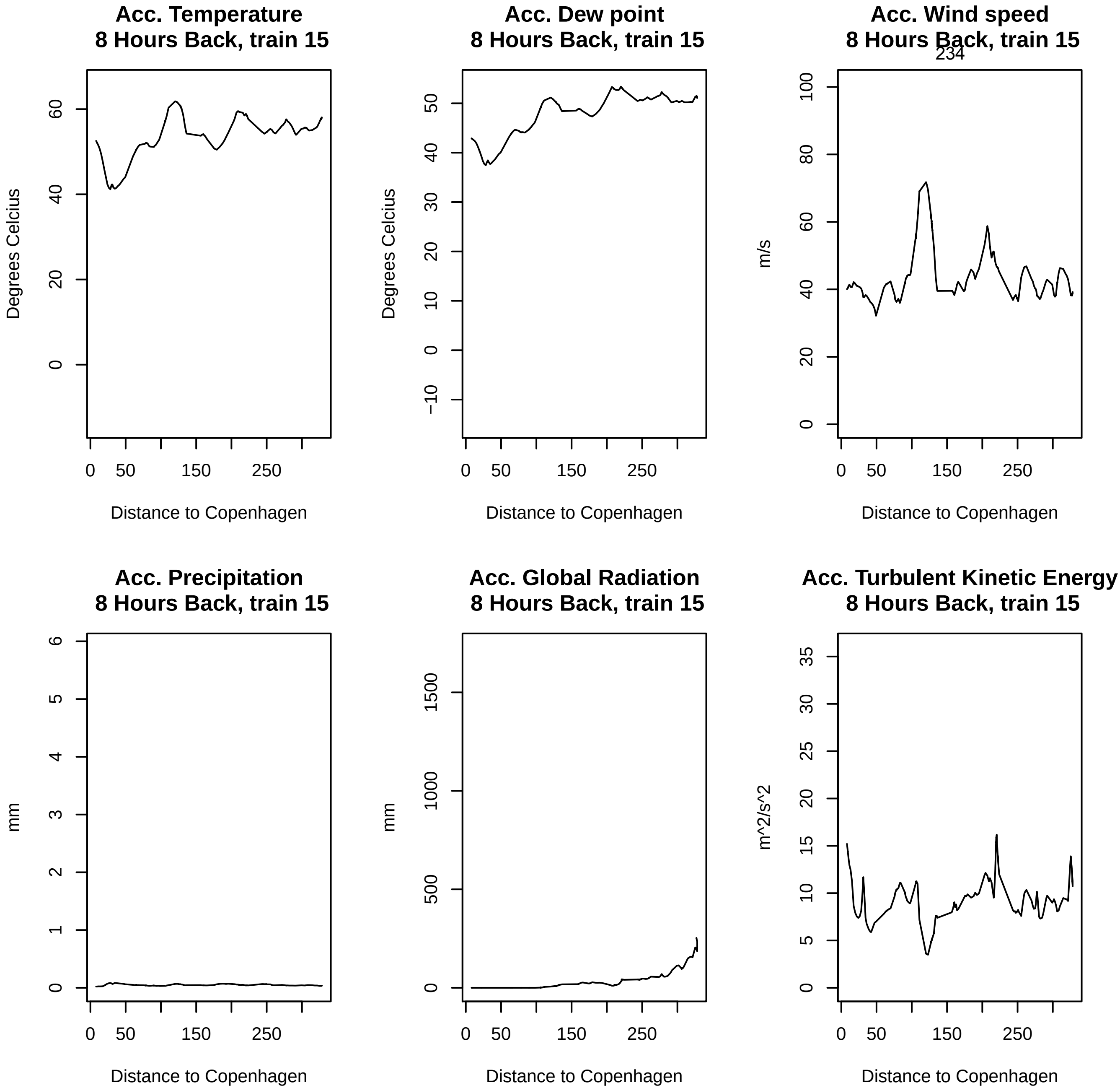

Acc. Temperature
4 Hours Back, train 15
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 15
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 15
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 15
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 15
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 15
m^2/s^2
0
5
10
15
20
0
50
150
250
Distance to Copenhagen

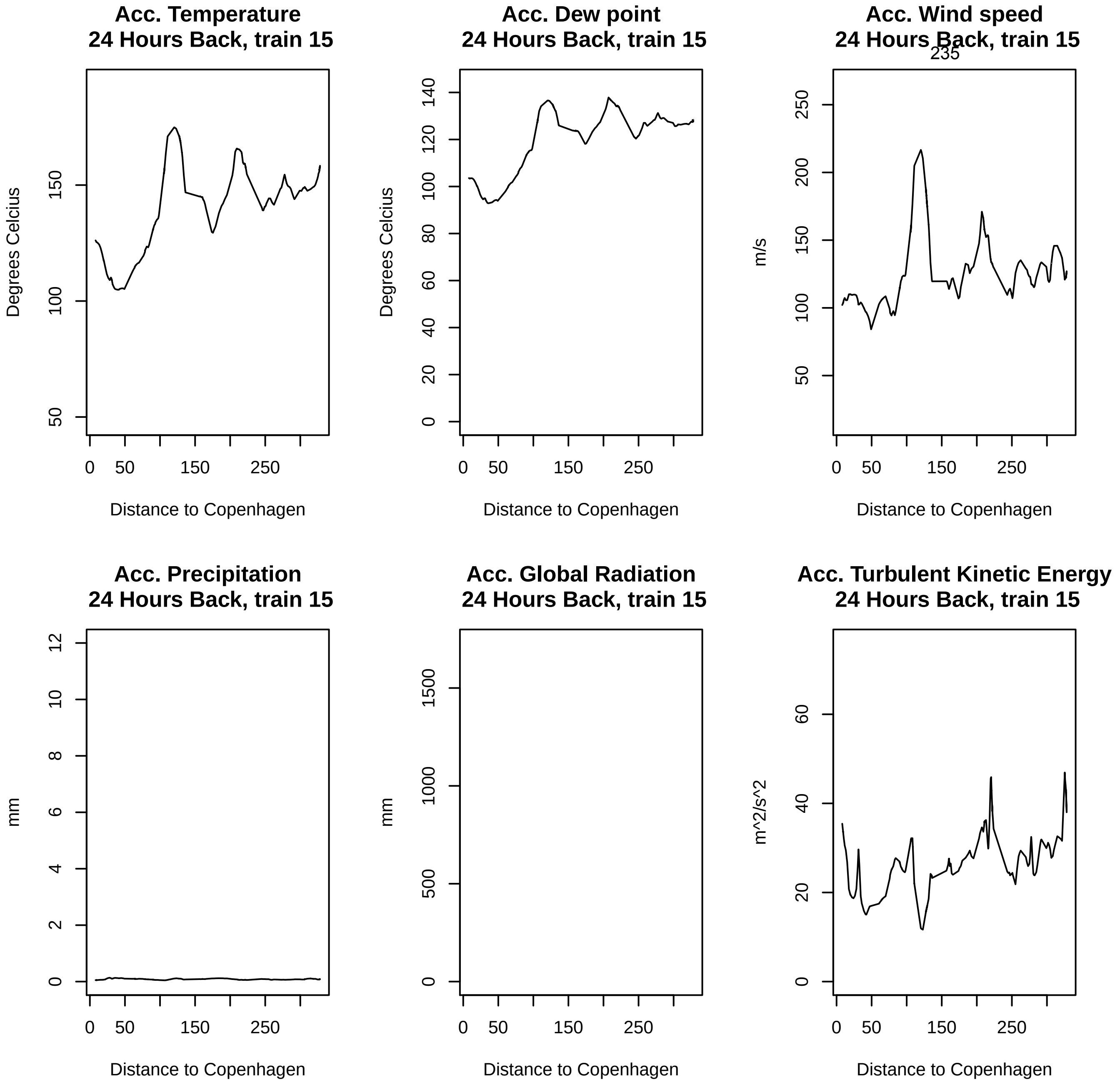

Acc. Temperature
5 Hours Back, train 15
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 15
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 15
231
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 15
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 15
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 15
m^2/s^2
Distance to Copenhagen



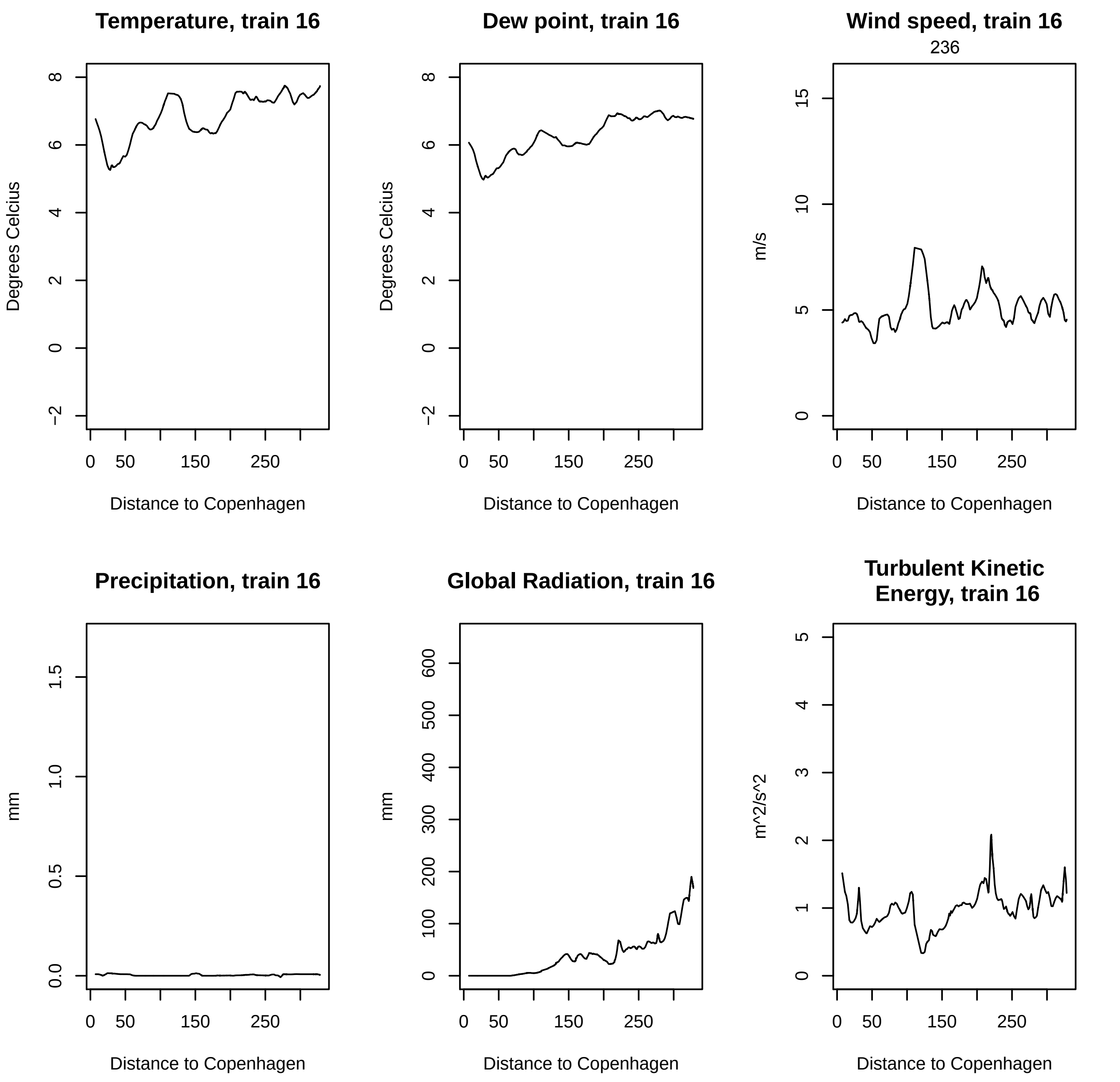
Acc. Temperature
6 Hours Back, train 15
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 15
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 15
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 15
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 15
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 15
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

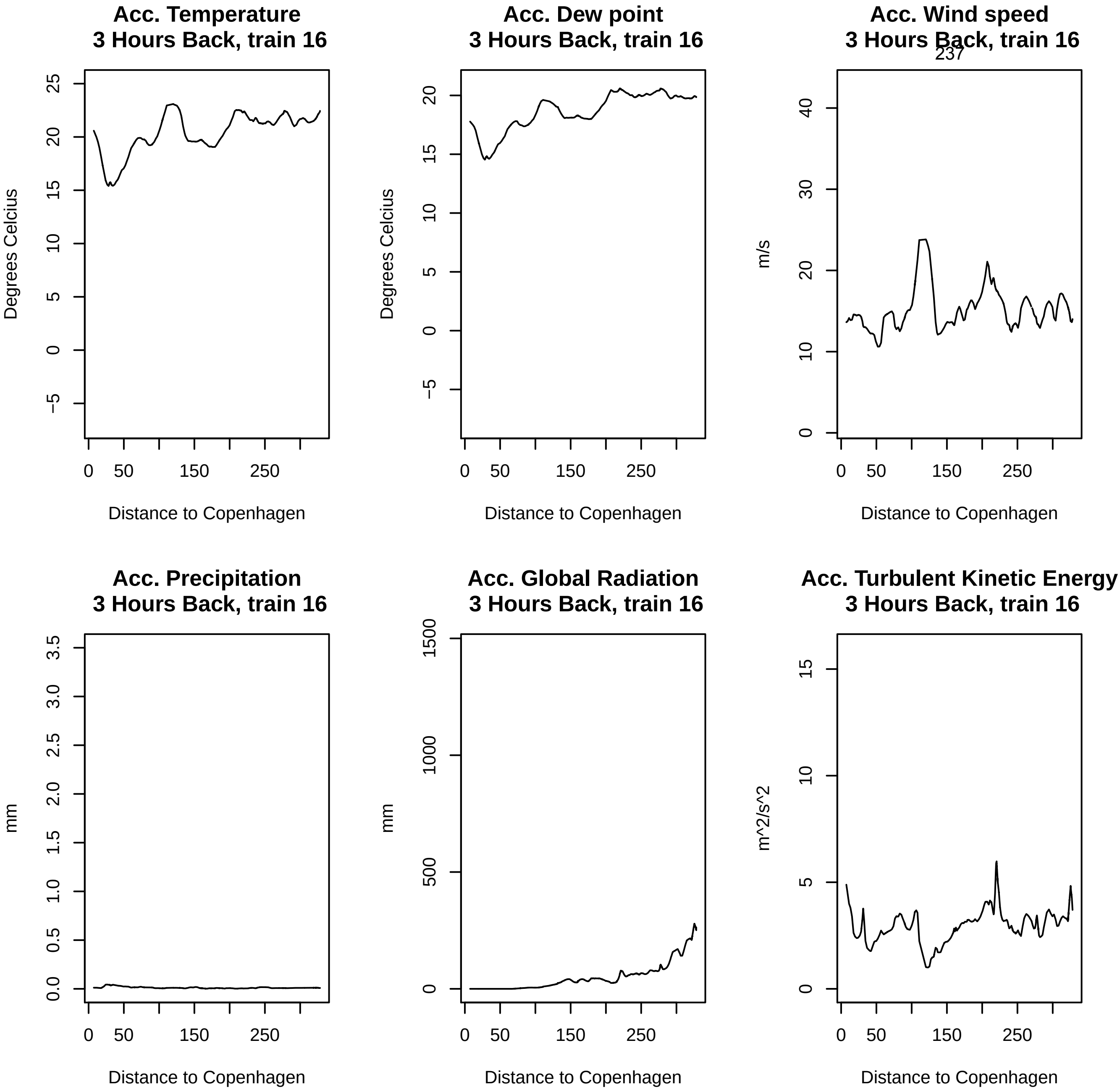

Acc. Temperature
7 Hours Back, train 15
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 15
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 15
233
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 15
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 15
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 15
m^2/s^2
Distance to Copenhagen

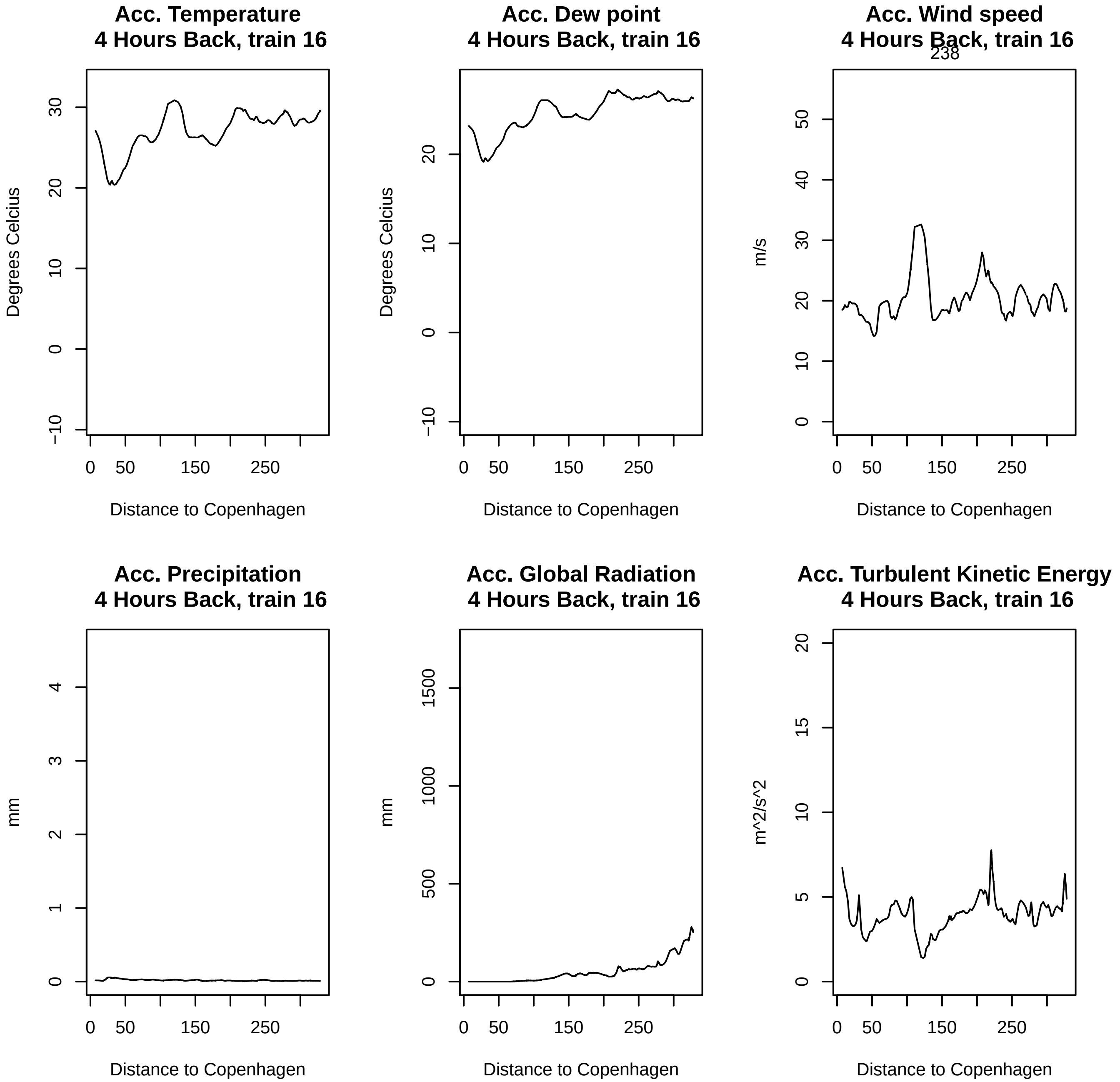

Acc. Temperature
8 Hours Back, train 15
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 15
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 15
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 15
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 15
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 15
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen

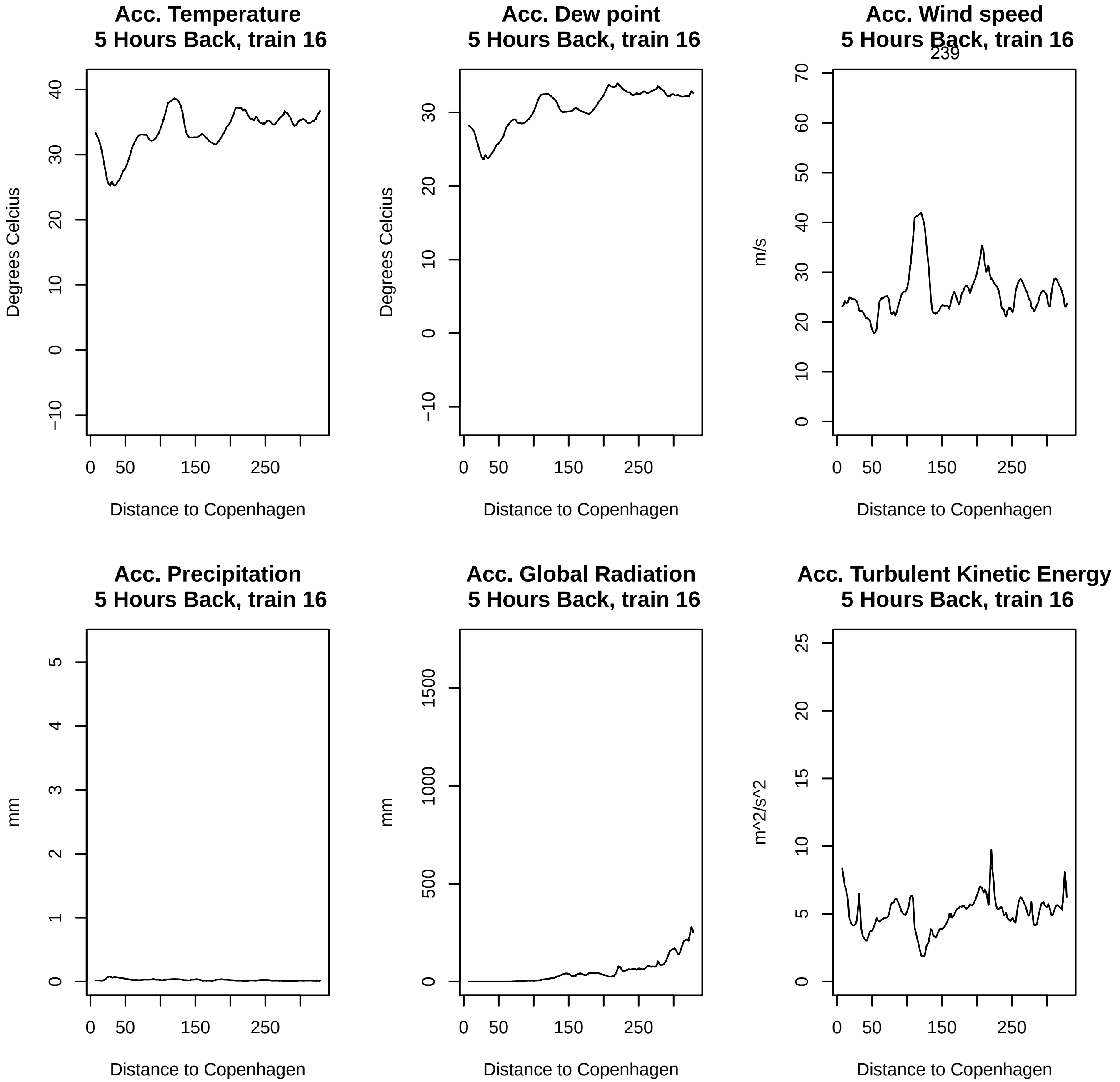


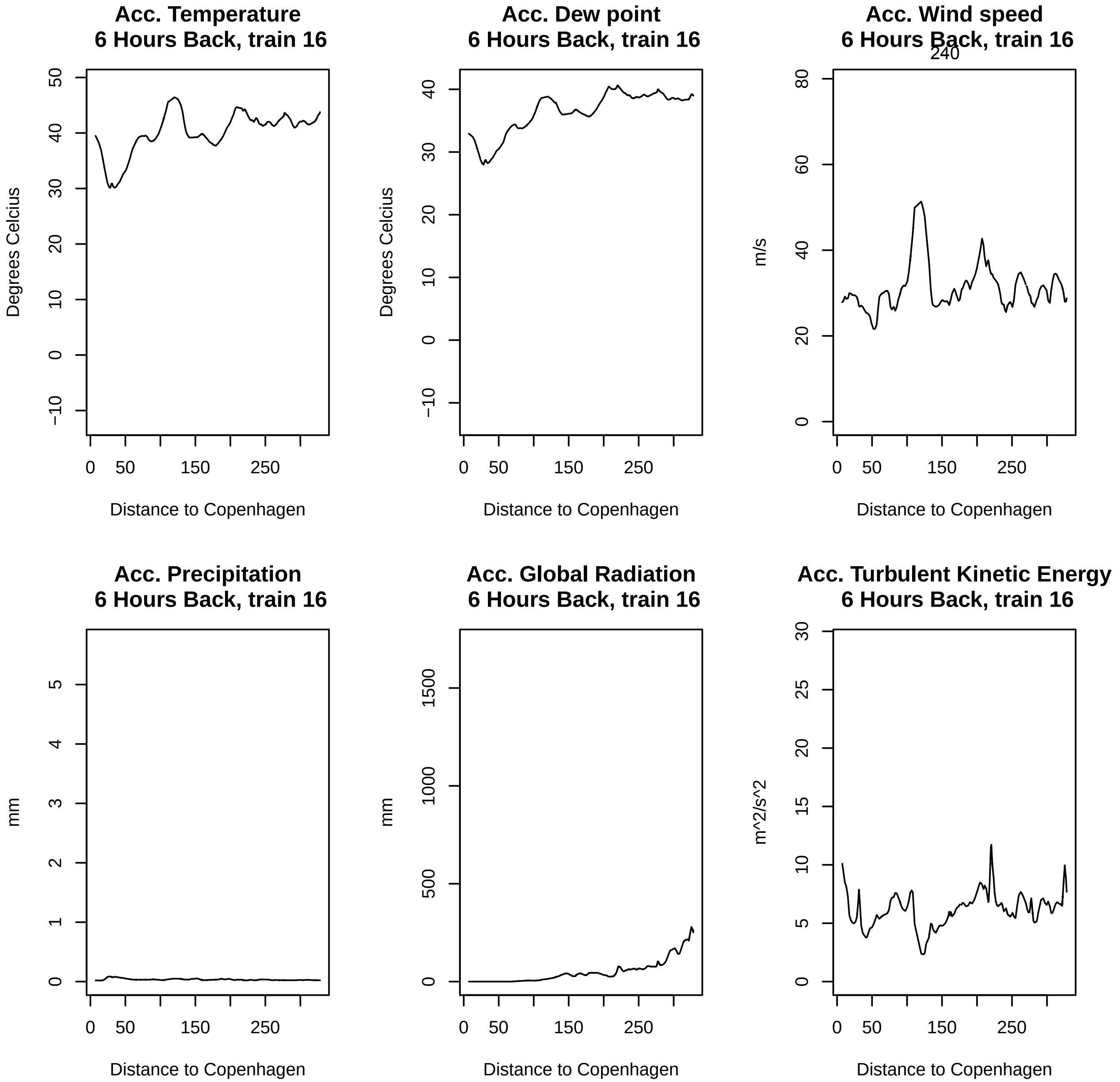
Acc. Temperature
24 Hours Back, train 15
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 15
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 15
235
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 15
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 15
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 15
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

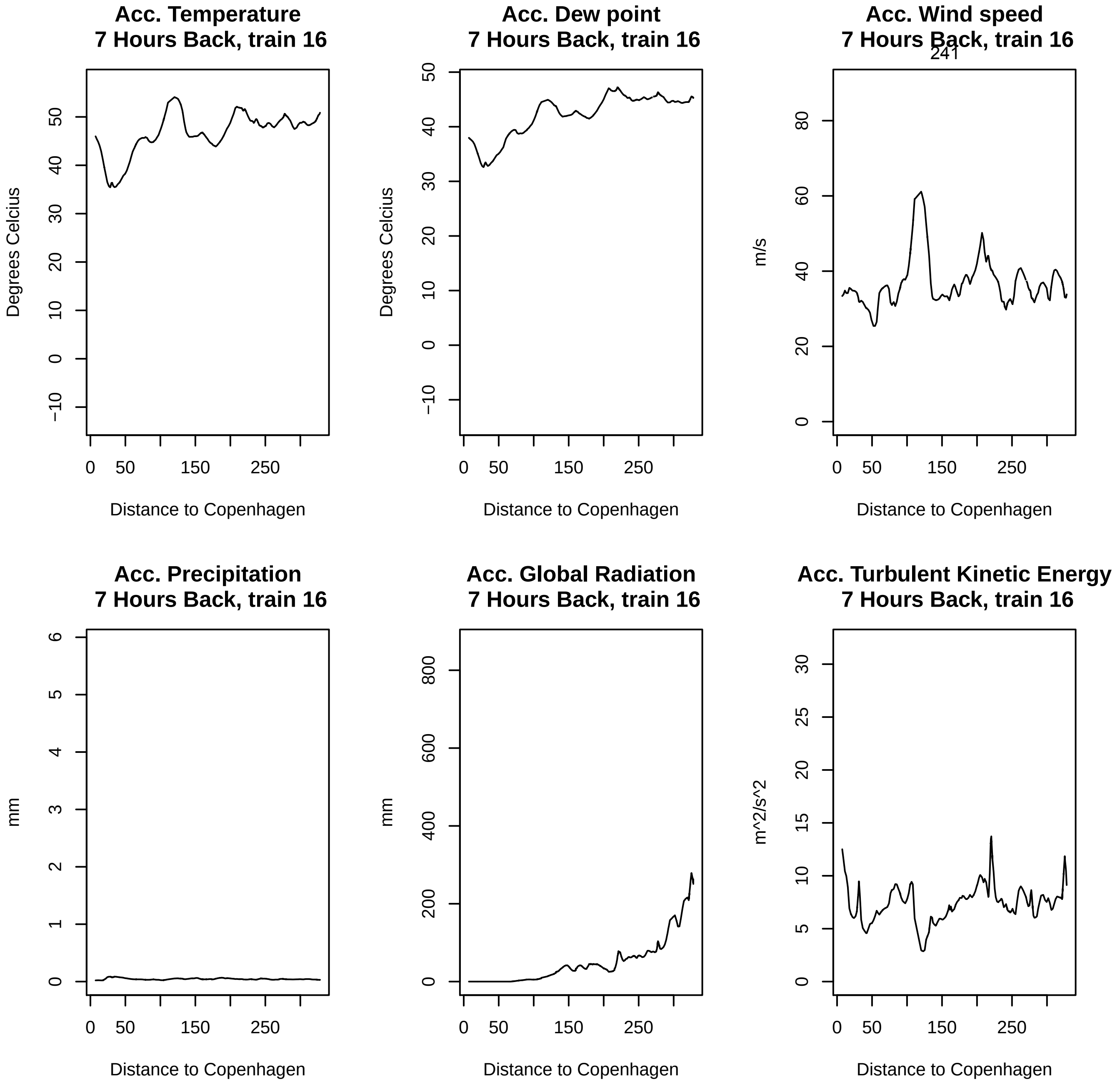

Temperature, train 16
Dew point, train 16
Wind speed, train 16
Precipitation, train 16
Global Radiation, train 16
Turbulent Kinetic Energy, train 16
Degrees Celcius
m/s
mm
m^2/s^2
Distance to Copenhagen
−2
0
2
4
6
8
0
5
10
15
0.0
0.5
1.0
1.5
100
200
300
400
500
600
1
2
3
4
5
50
150
250

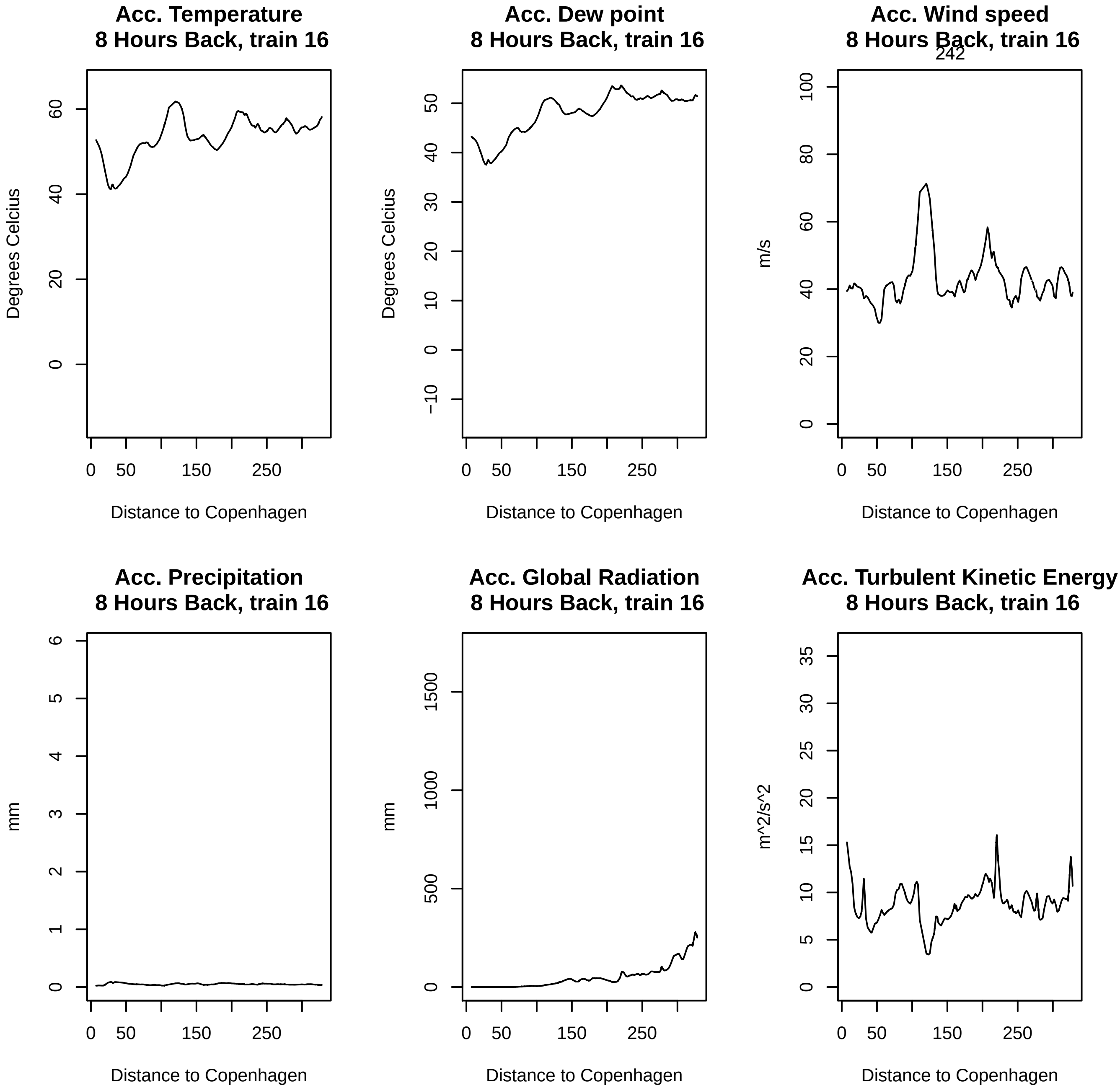

Acc. Temperature
3 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 16
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

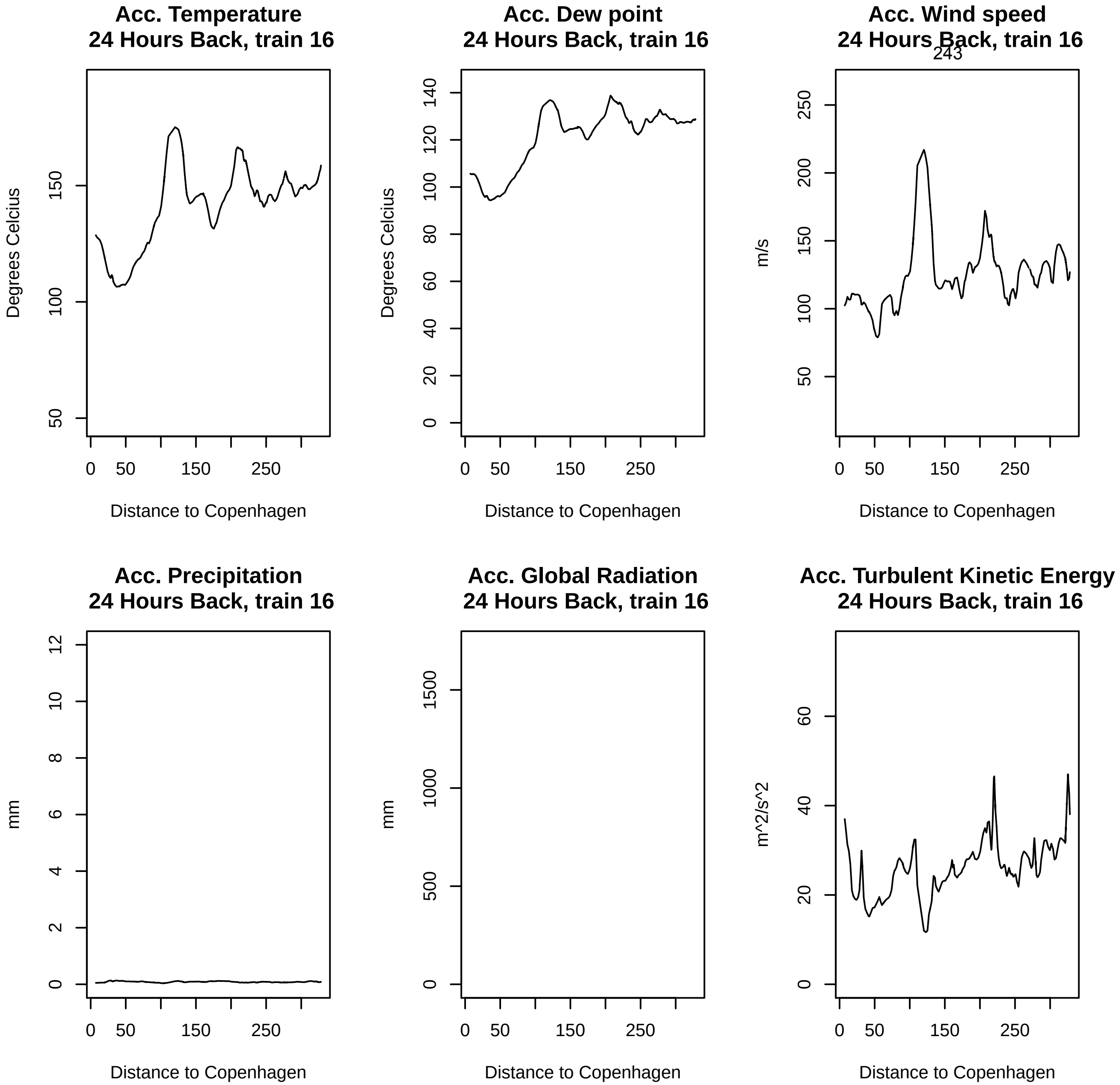

Acc. Temperature
4 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 16
238
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

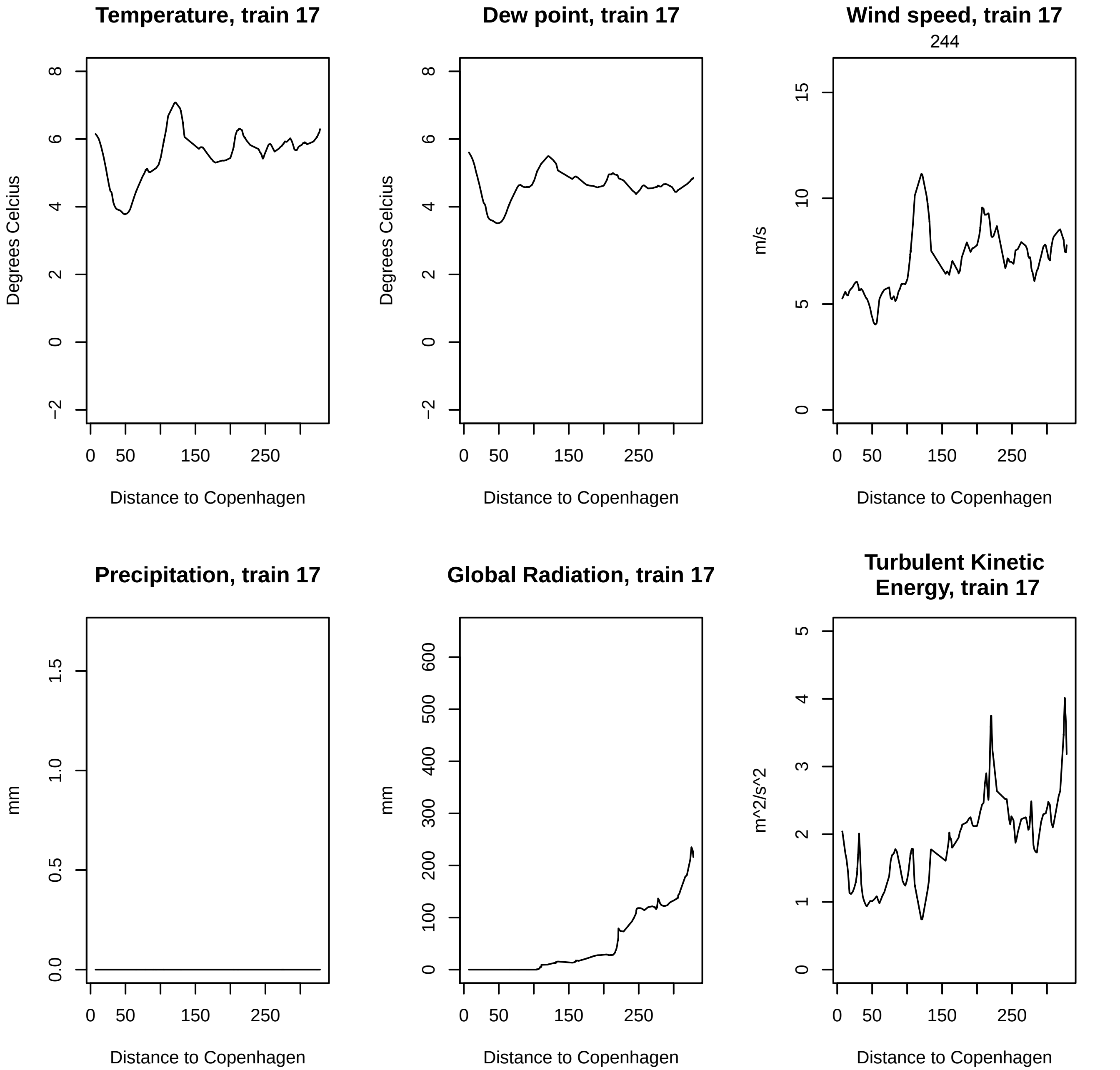

Acc. Temperature
5 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 16
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

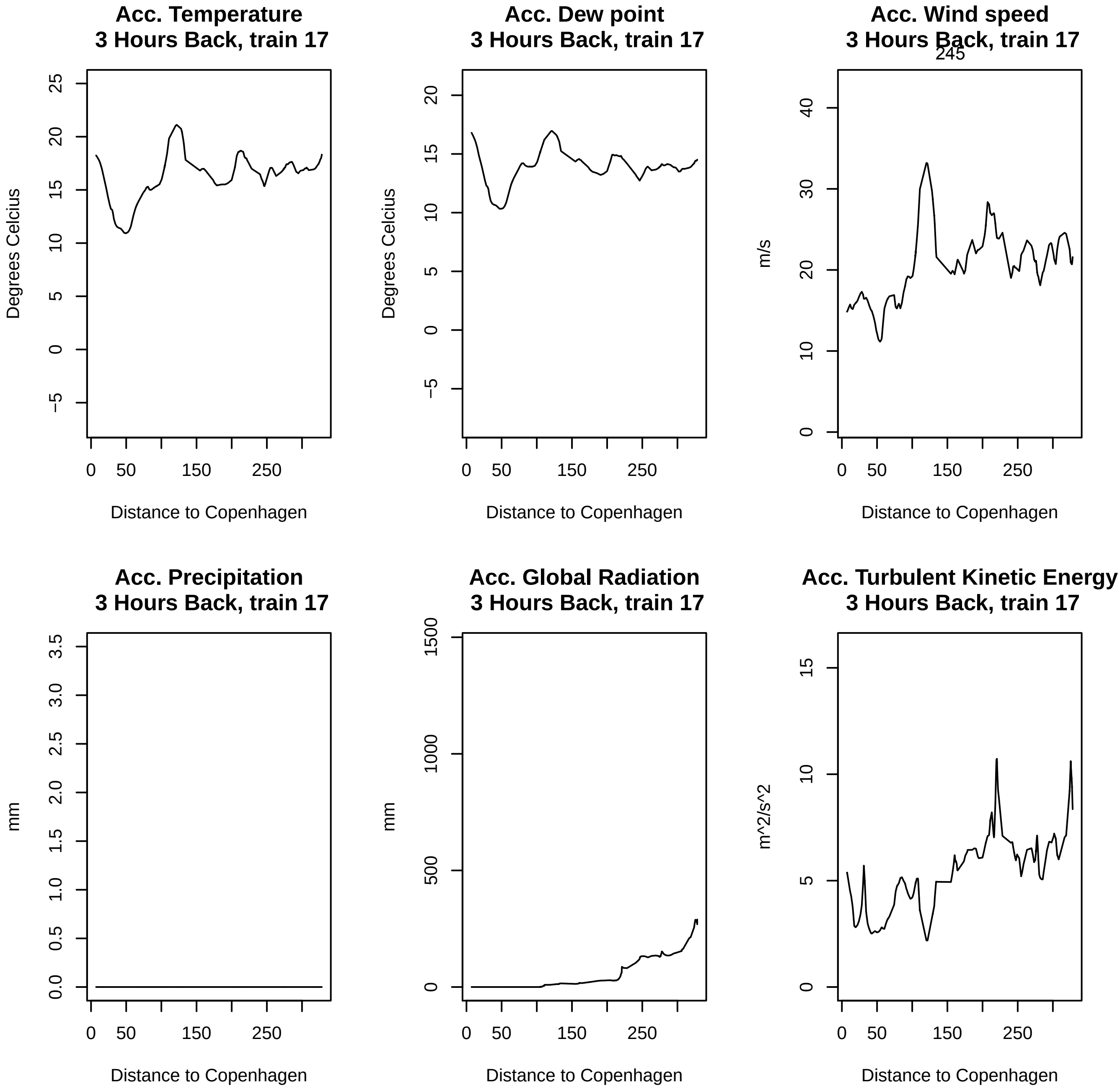

Acc. Temperature
6 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 16
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

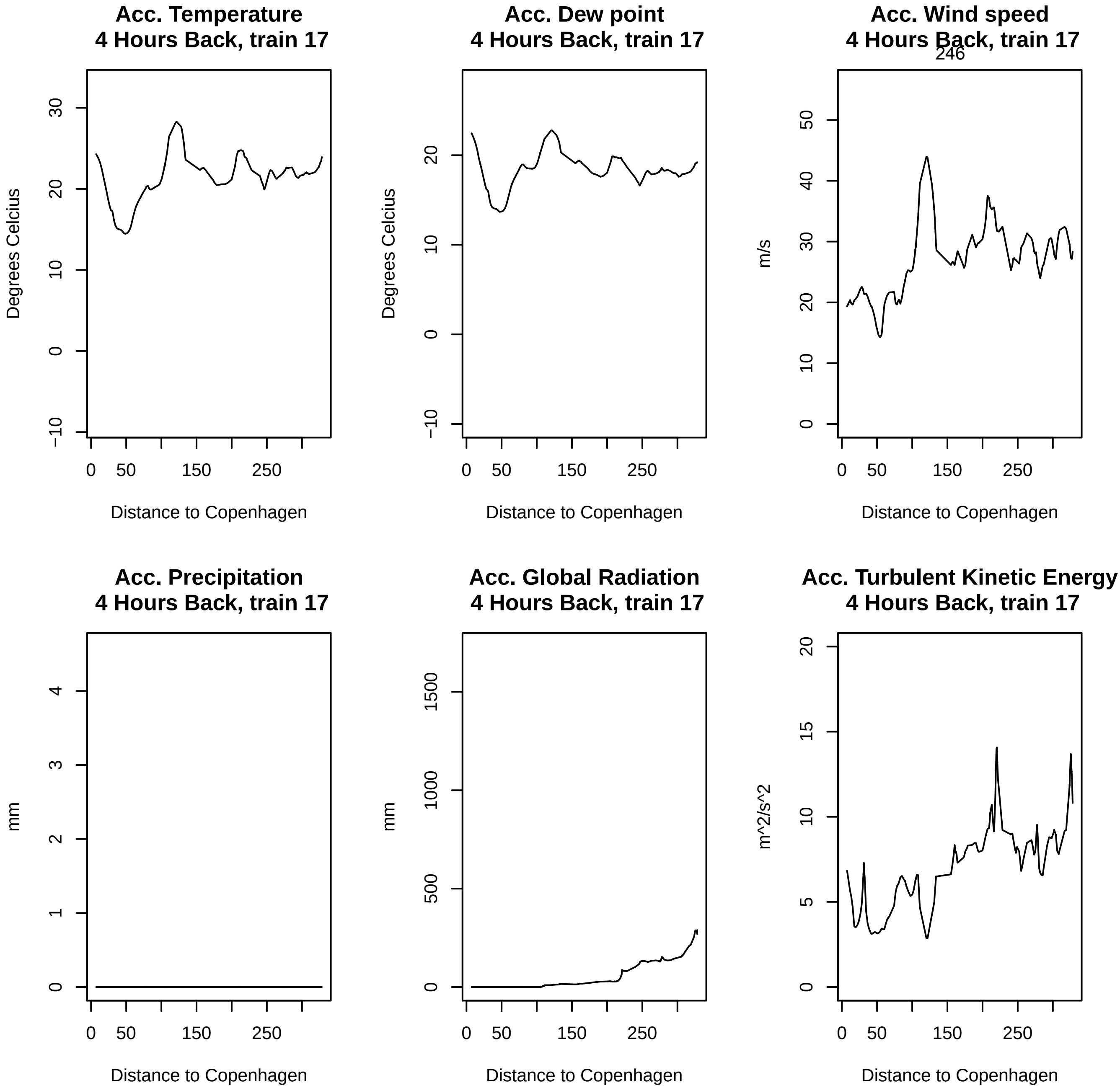

Acc. Temperature
7 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 16
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

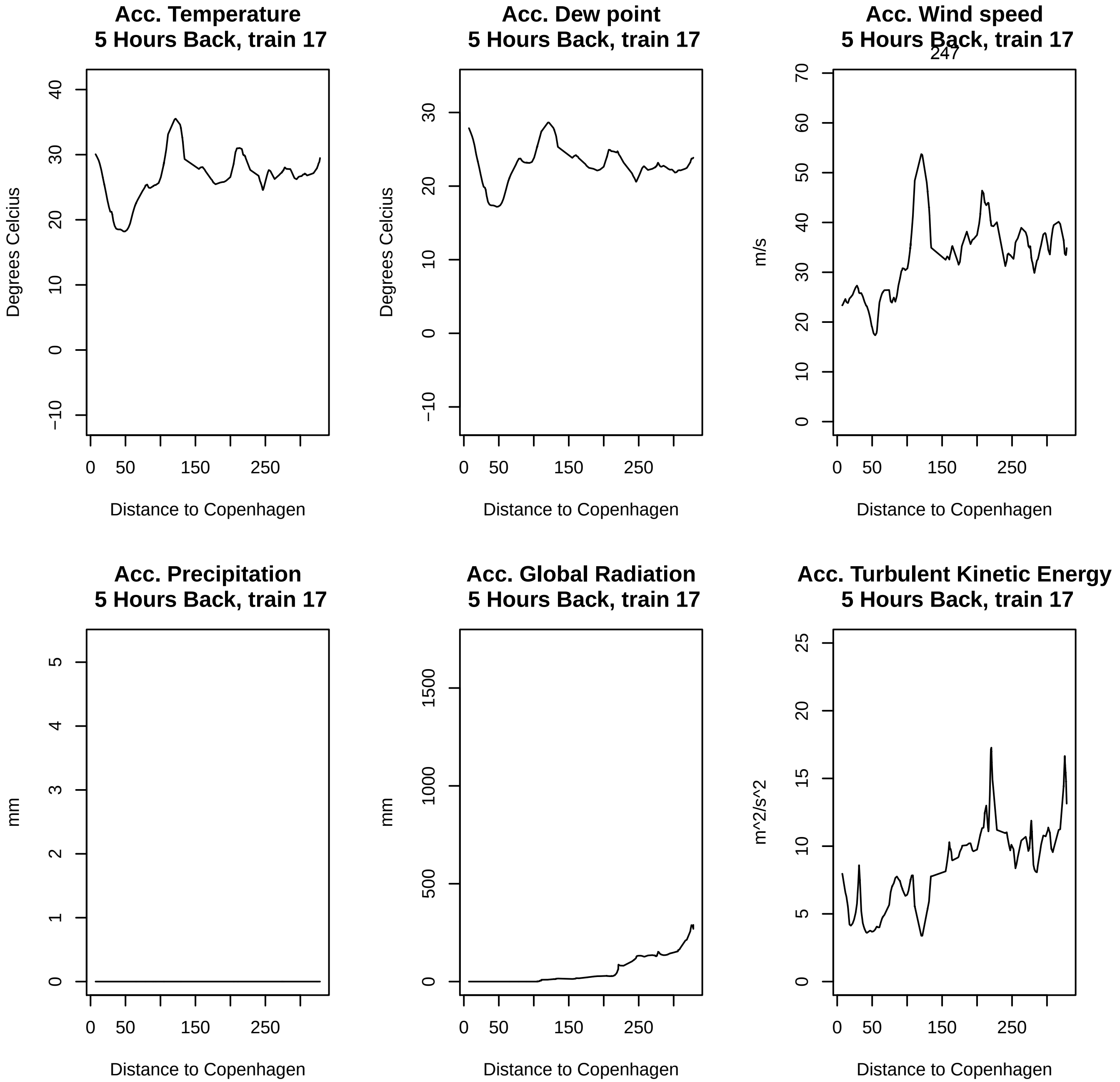

Acc. Temperature
8 Hours Back, train 16
Degrees Celcius
60
40
20
0
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 16
Degrees Celcius
50
40
30
20
10
0
−10
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 16
m/s
100
80
60
40
20
0
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 16
mm
6
5
4
3
2
1
0
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 16
mm
1500
1000
500
0
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 16
m^2/s^2
35
30
25
20
15
10
5
0
0
50
150
250
Distance to Copenhagen

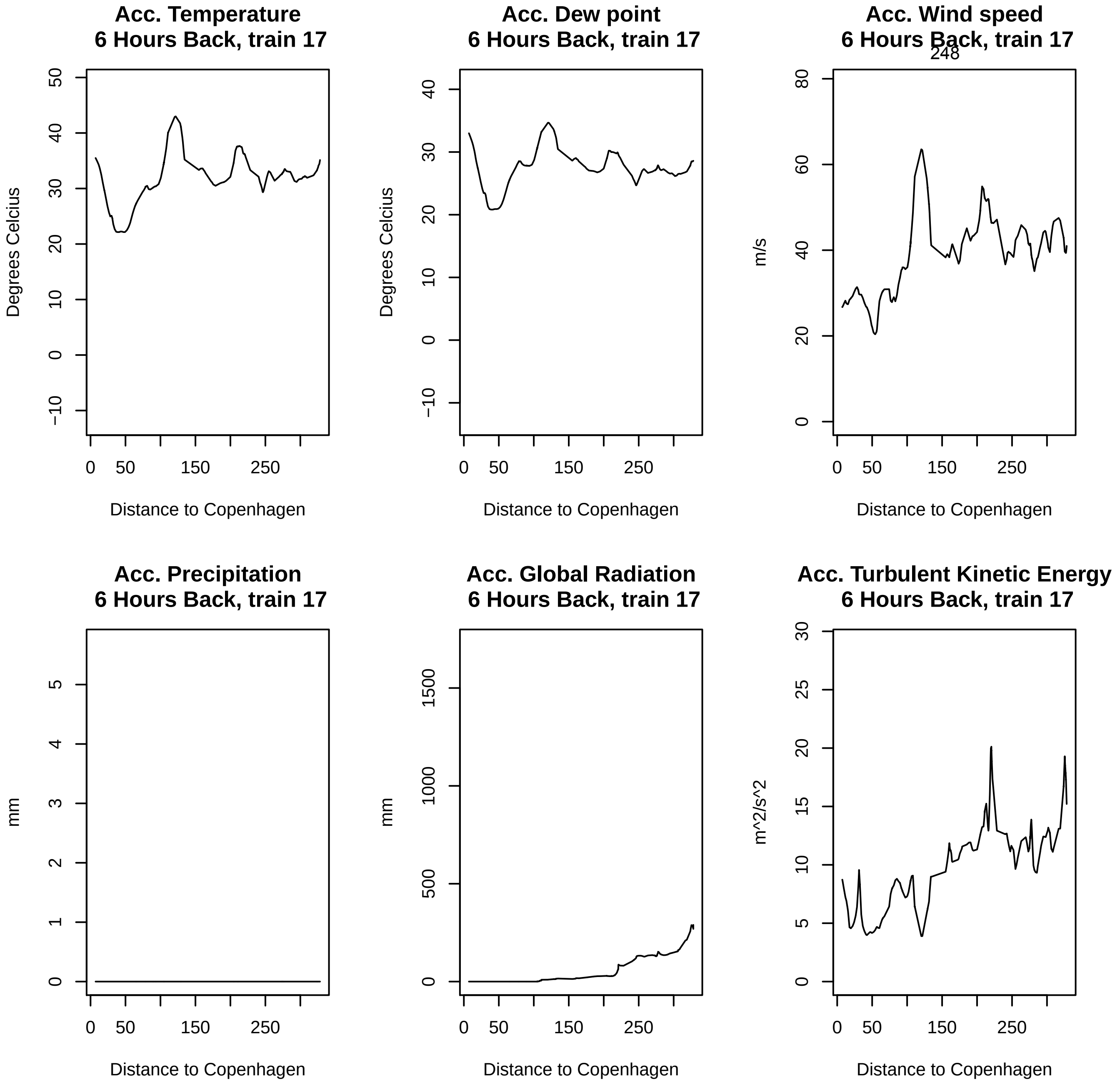

Acc. Temperature
24 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 16
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 16
243
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 16
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 16
m^2/s^2
Distance to Copenhagen

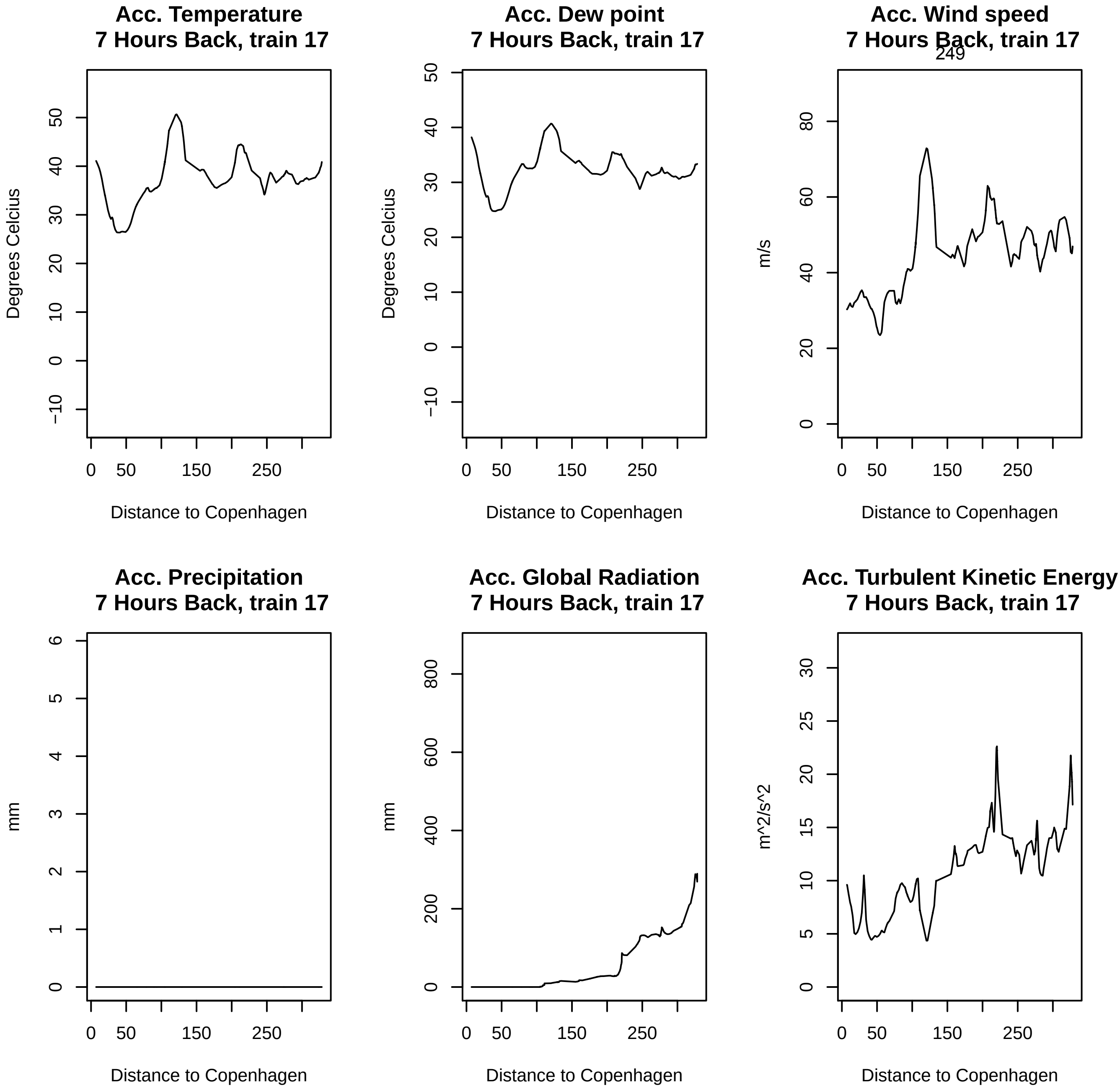

Temperature, train 17
Dew point, train 17
Wind speed, train 17
244
Precipitation, train 17
Global Radiation, train 17
Turbulent Kinetic Energy, train 17
Degrees Celcius
m/s
mm
m^2/s^2
Distance to Copenhagen
−2
0
2
4
6
8
5
10
15
0.0
0.5
1.0
1.5
100
200
300
400
500
600
1
3
50
150
250


Acc. Temperature
3 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 17
245
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 17
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 17
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 17
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 17
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 17
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 17
247
m/s
0
10
20
30
40
50
60
70
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 17
mm
0
1
2
3
4
5
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 17
mm
0
500
1000
1500
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 17
m^2/s^2
0
5
10
15
20
25
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 17
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 17
m^2/s^2
Distance to Copenhagen
0
50
150
250



Acc. Temperature
7 Hours Back, train 17
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 17
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 17
249
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 17
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 17
mm
0
200
400
600
800
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 17
m^2/s^2
0
5
10
15
20
25
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0
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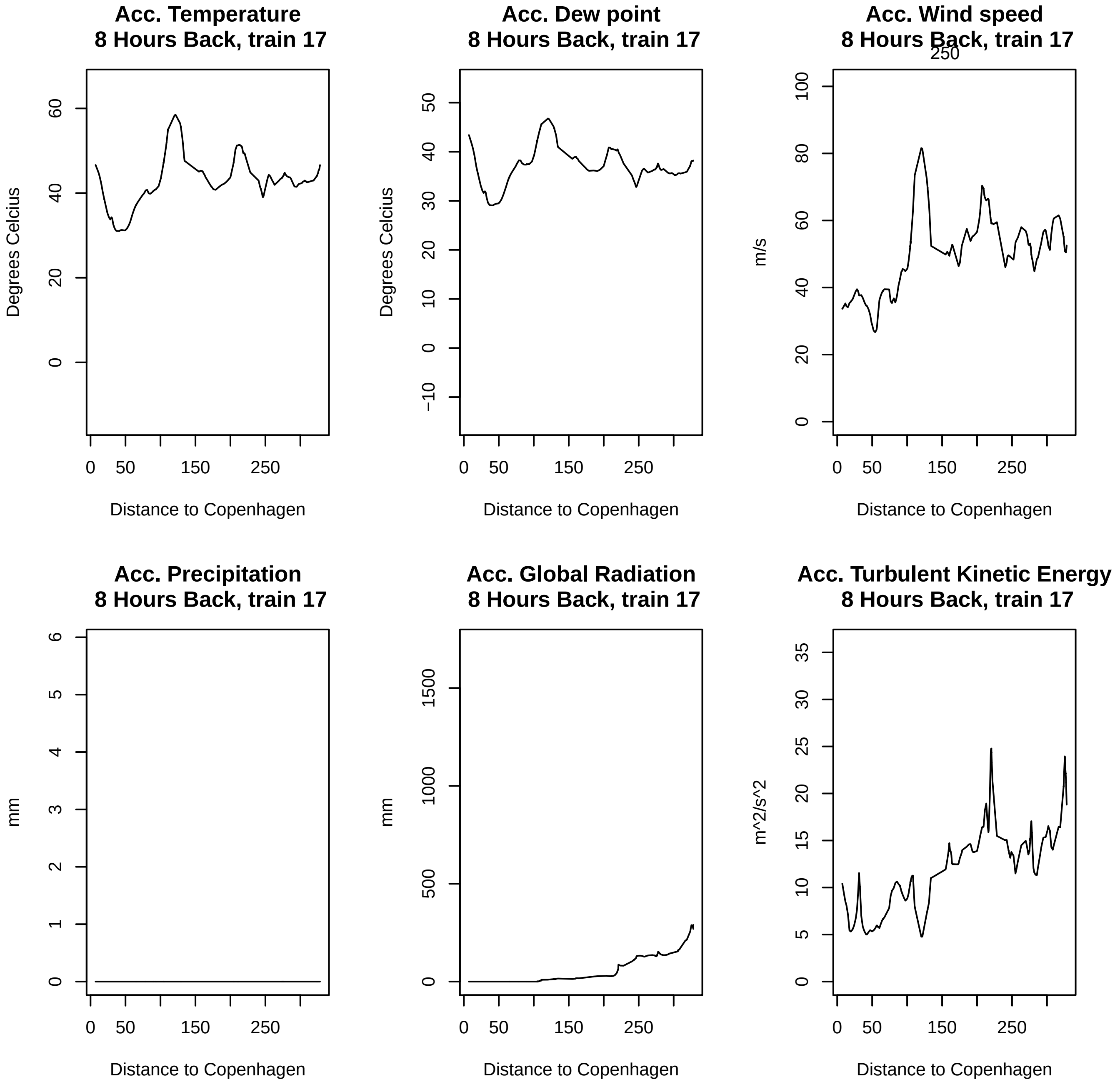
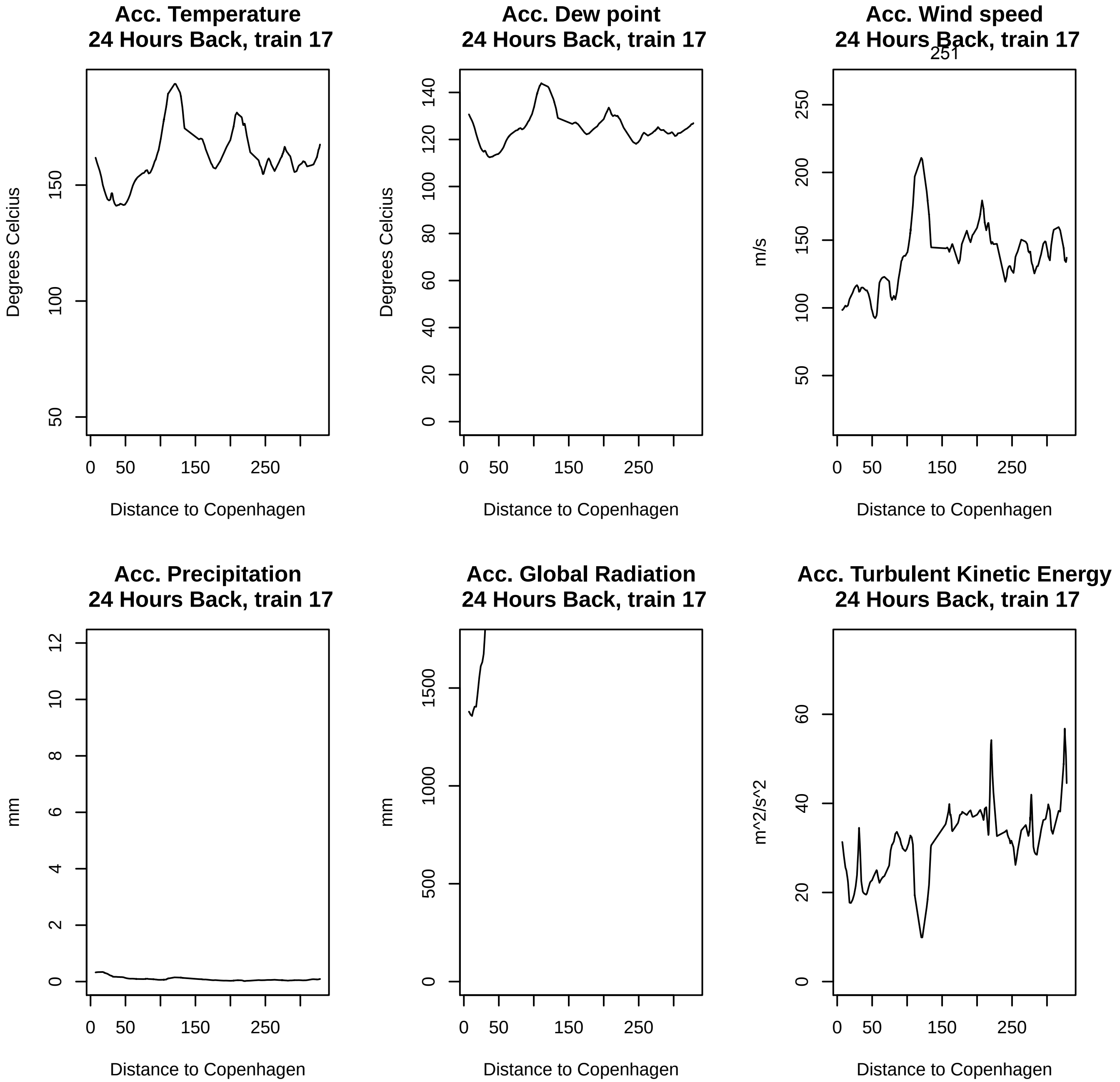
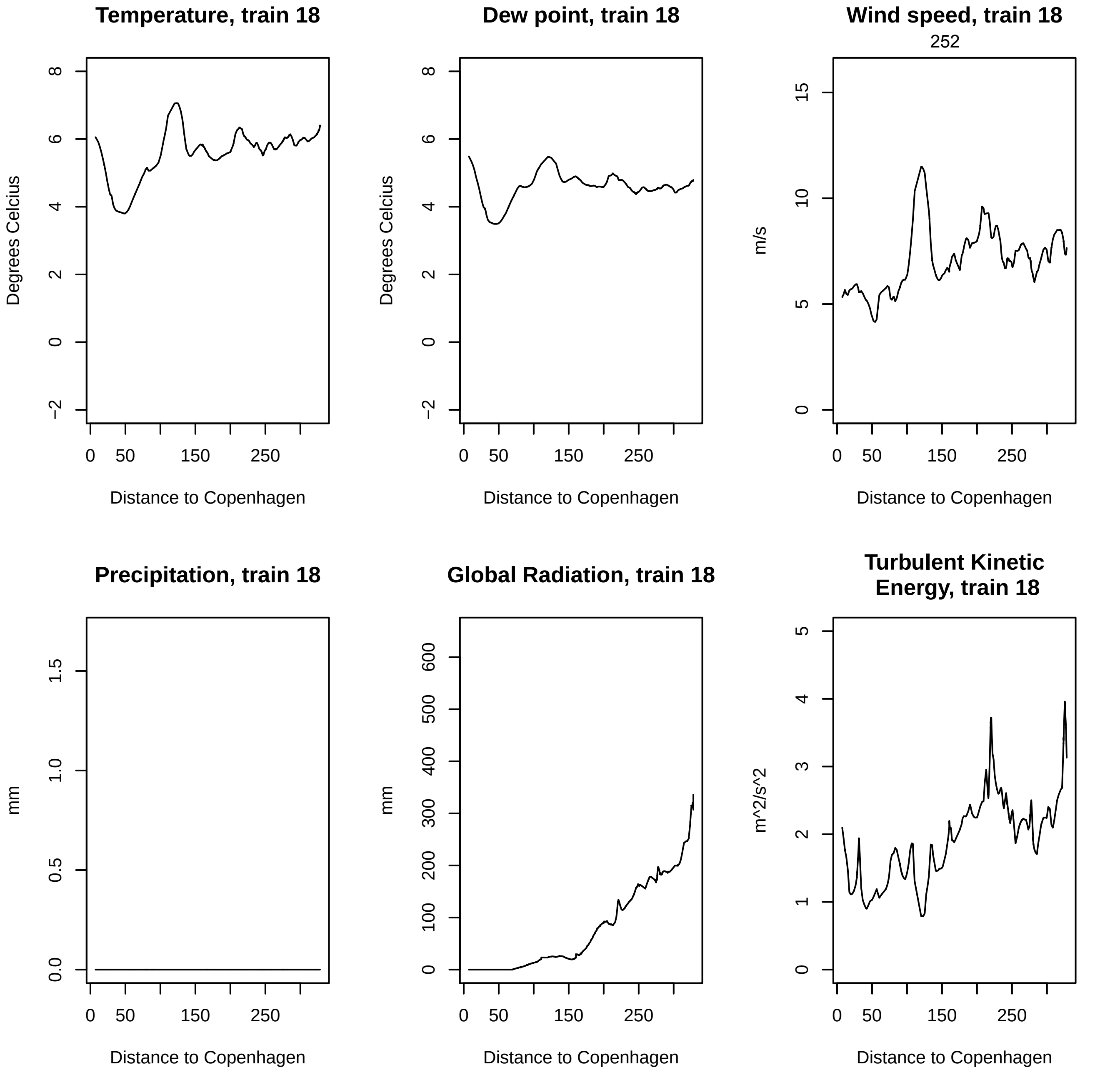
150
250
Distance to Copenhagen

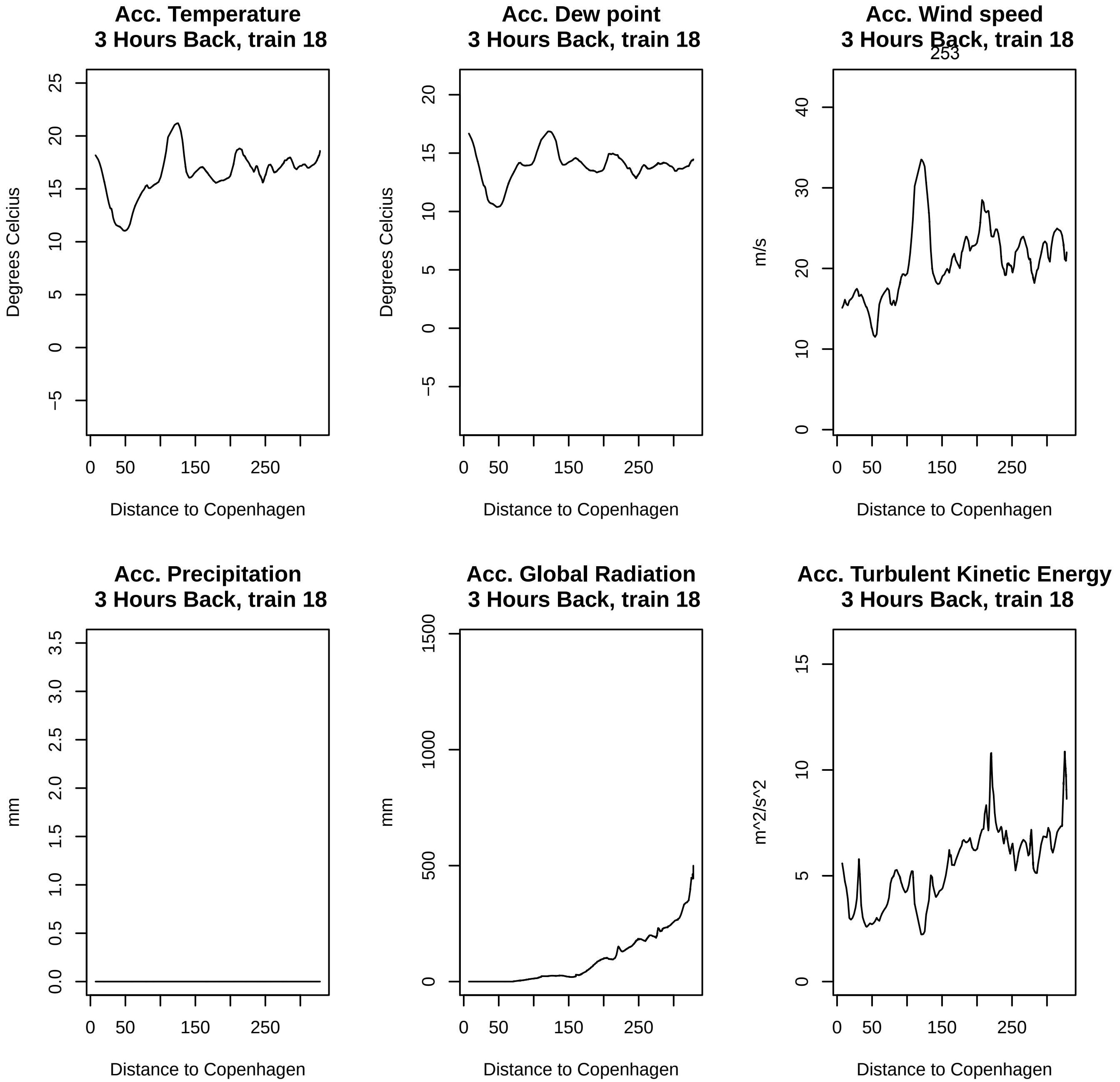

Acc. Temperature
8 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 17
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 17
250
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 17
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 17
m^2/s^2
Distance to Copenhagen

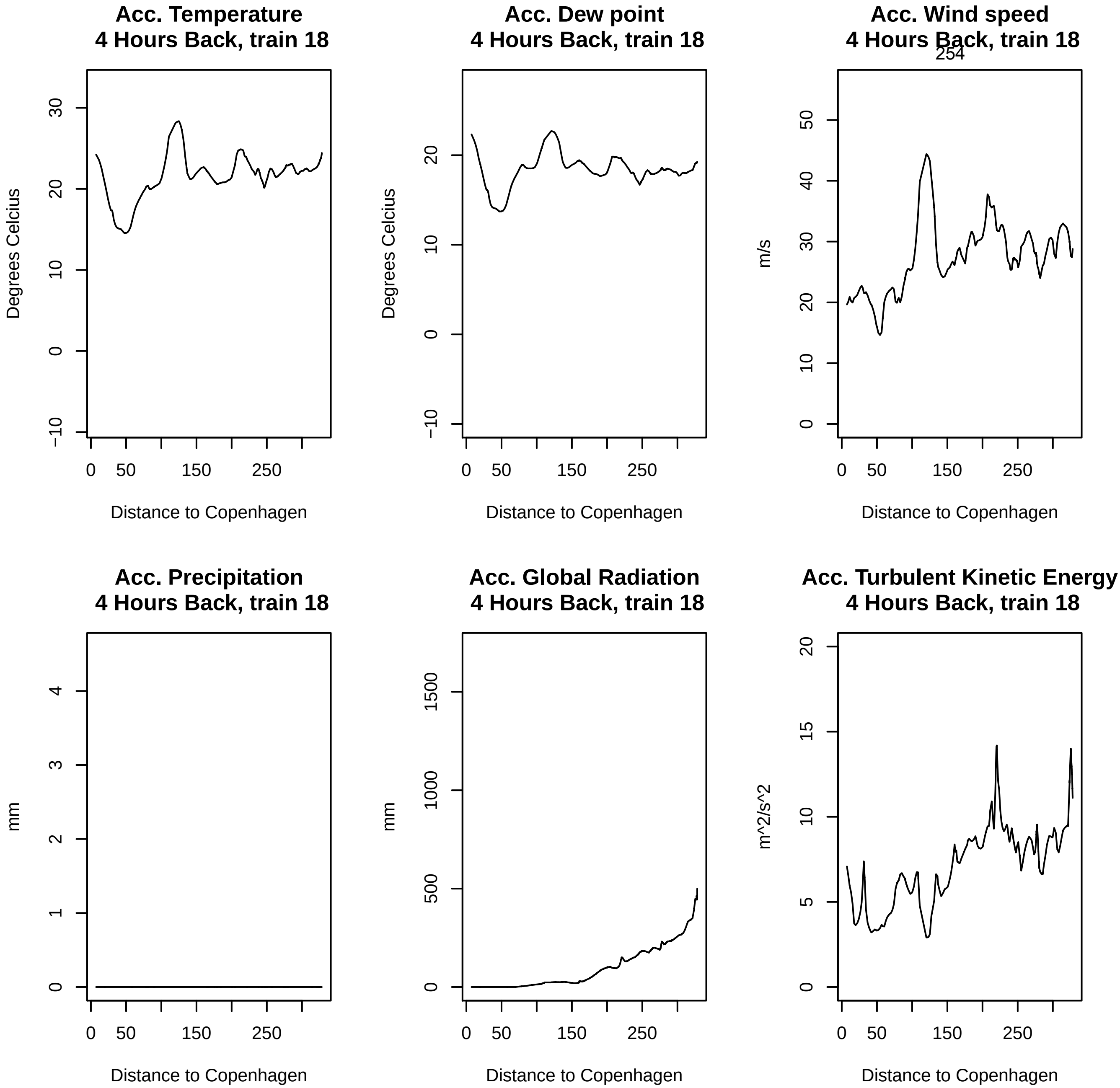


Acc. Temperature
24 Hours Back, train 17
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 17
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 17
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 17
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 17
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 17
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen



Temperature, train 18
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 18
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Wind speed, train 18
252
m/s
0
5
10
15
0
50
150
250
Distance to Copenhagen
Precipitation, train 18
mm
0.0
0.5
1.0
1.5
0
50
150
250
Distance to Copenhagen
Global Radiation, train 18
mm
0
100
200
300
400
500
600
0
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 18
m^2/s^2
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 18
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 18
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 18
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 18
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 18
m/s
0
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20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 18
mm
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0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 18
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 18
m^2/s^2
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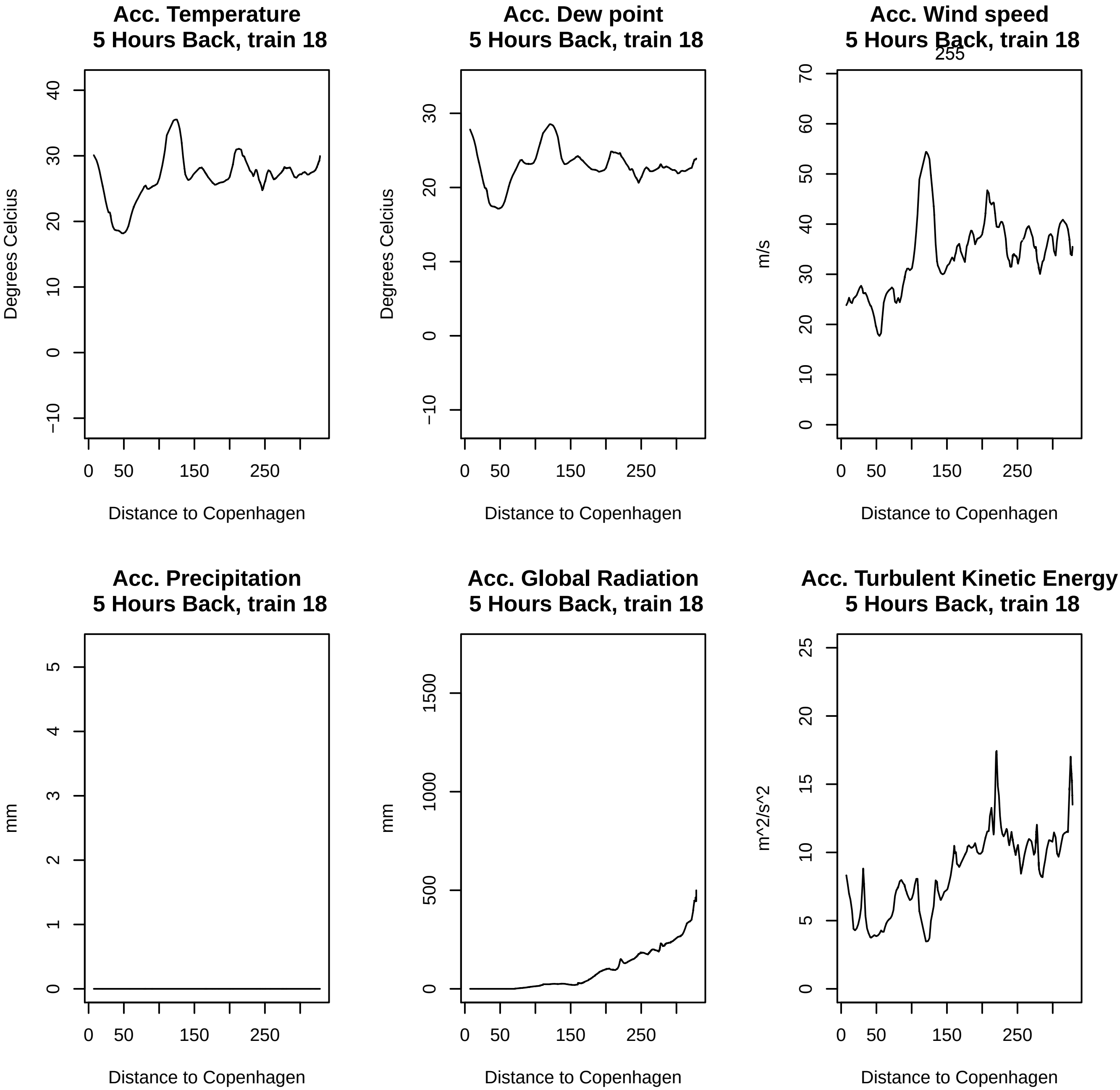
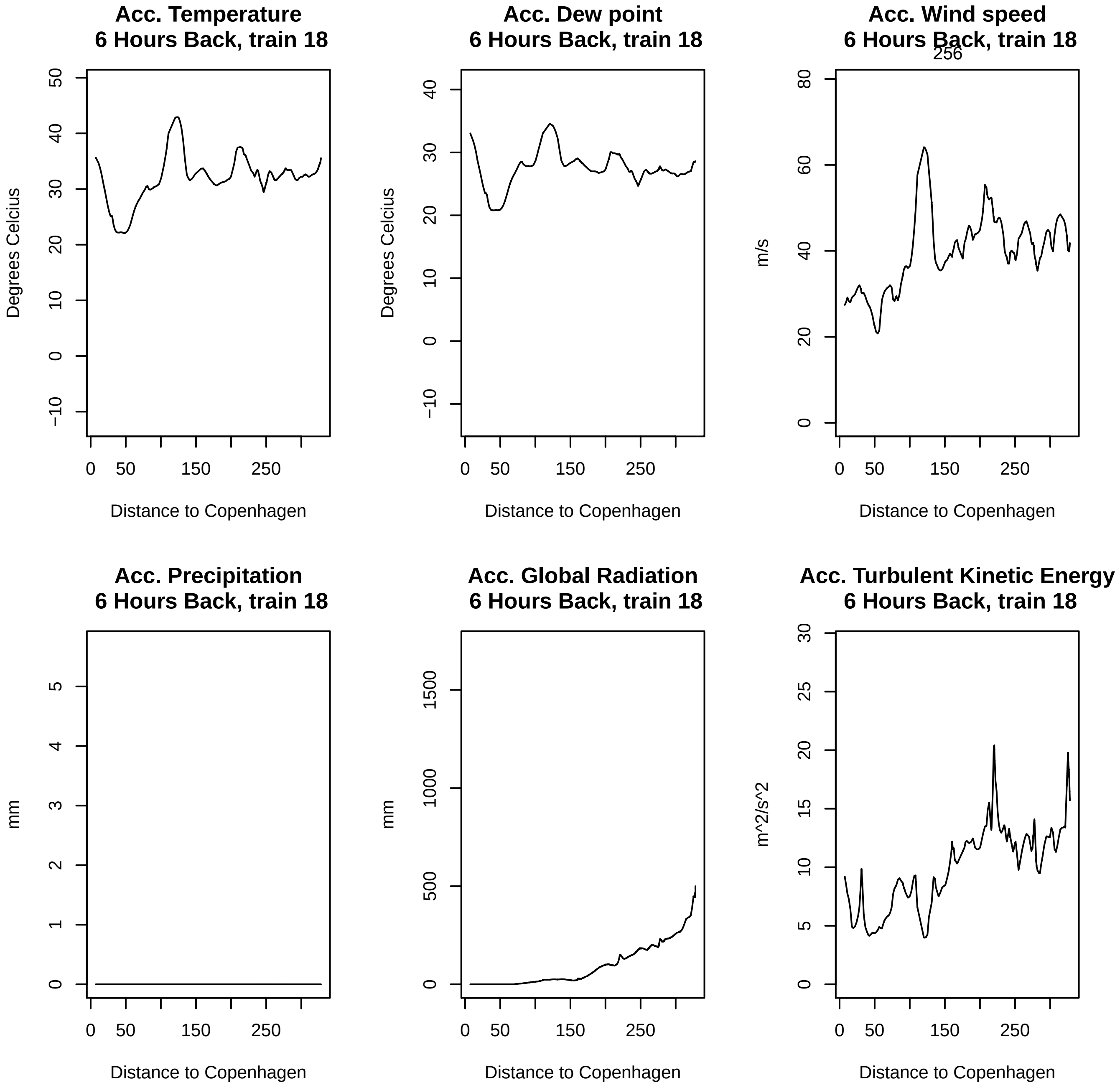
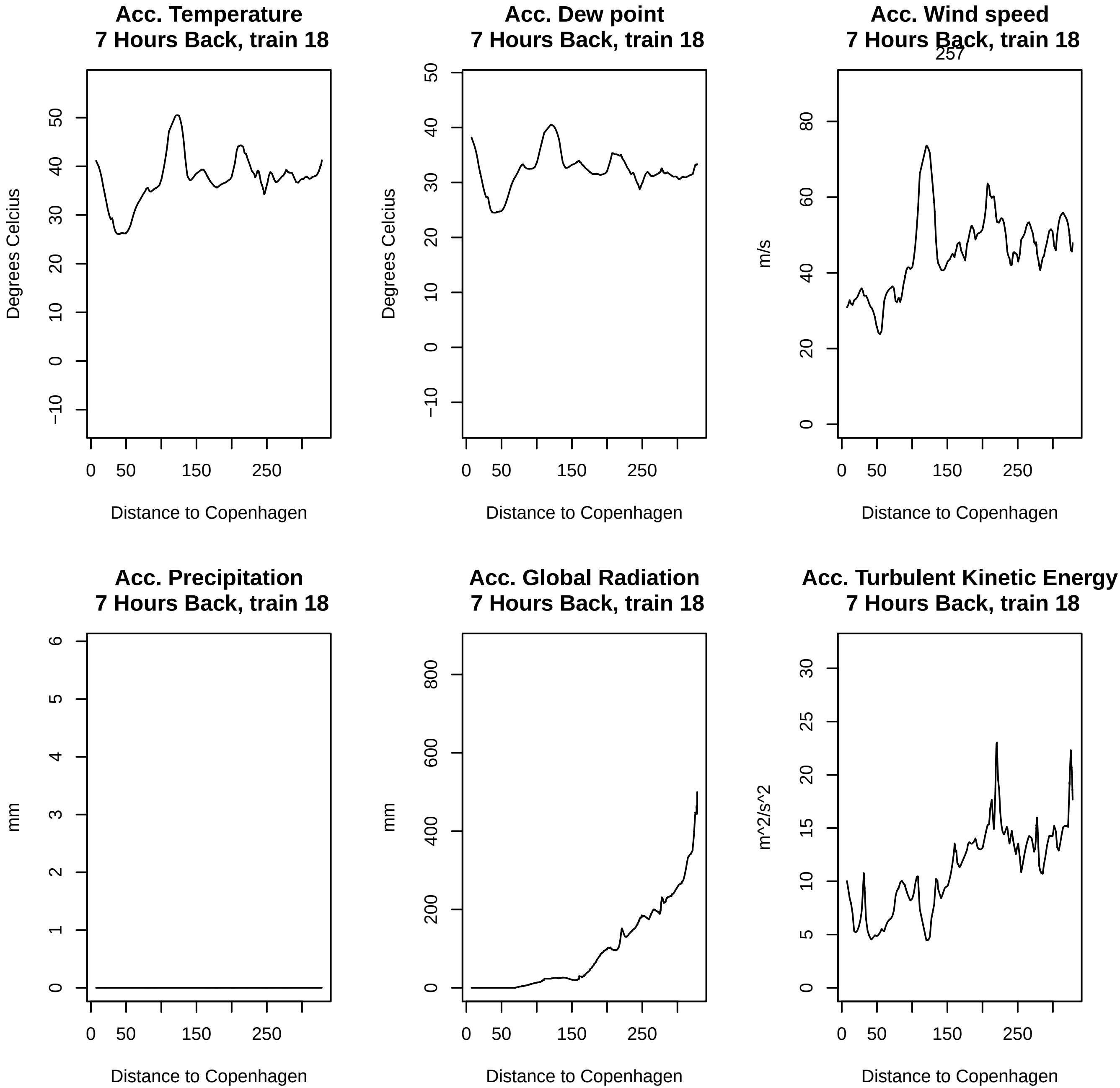
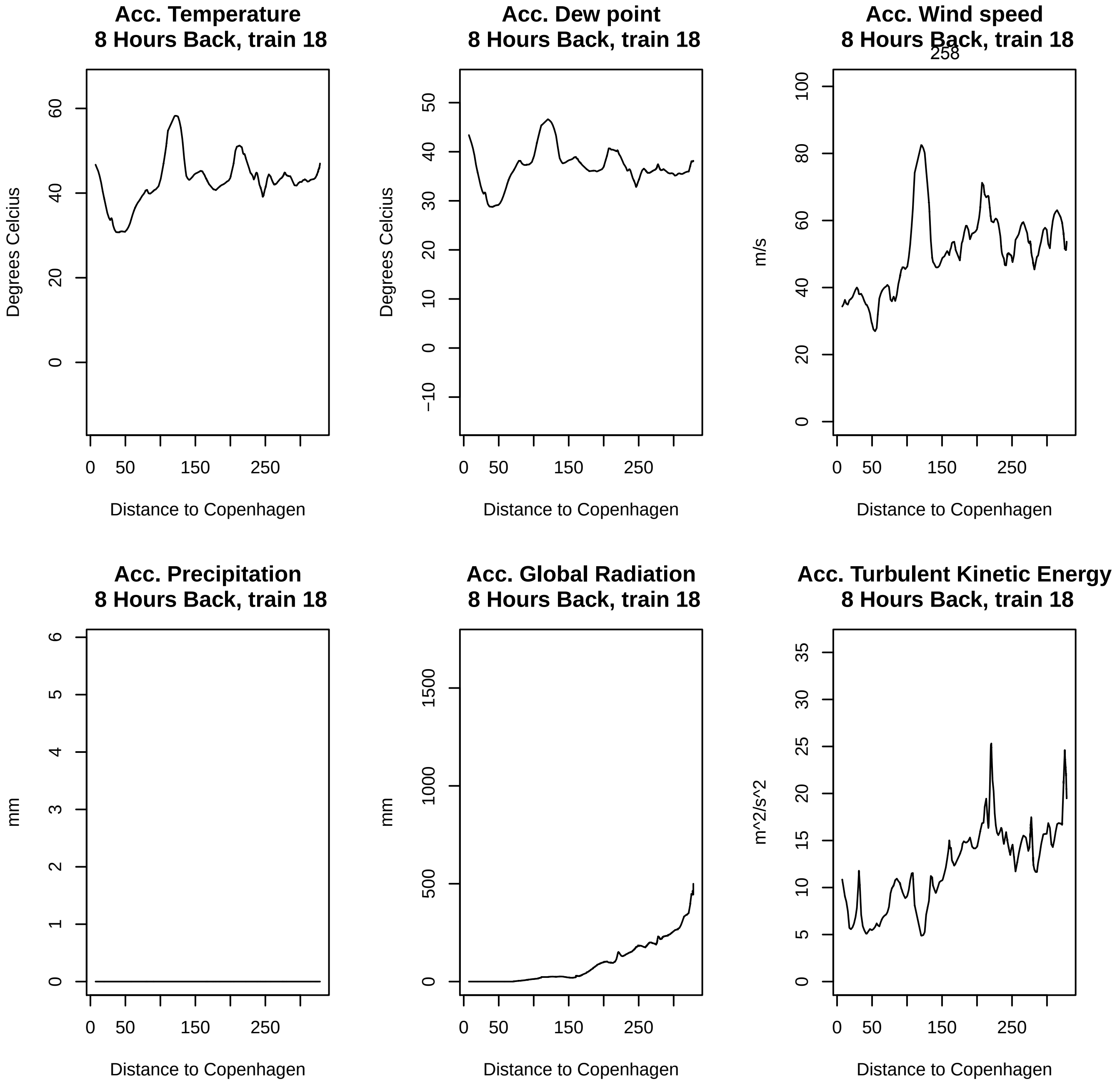
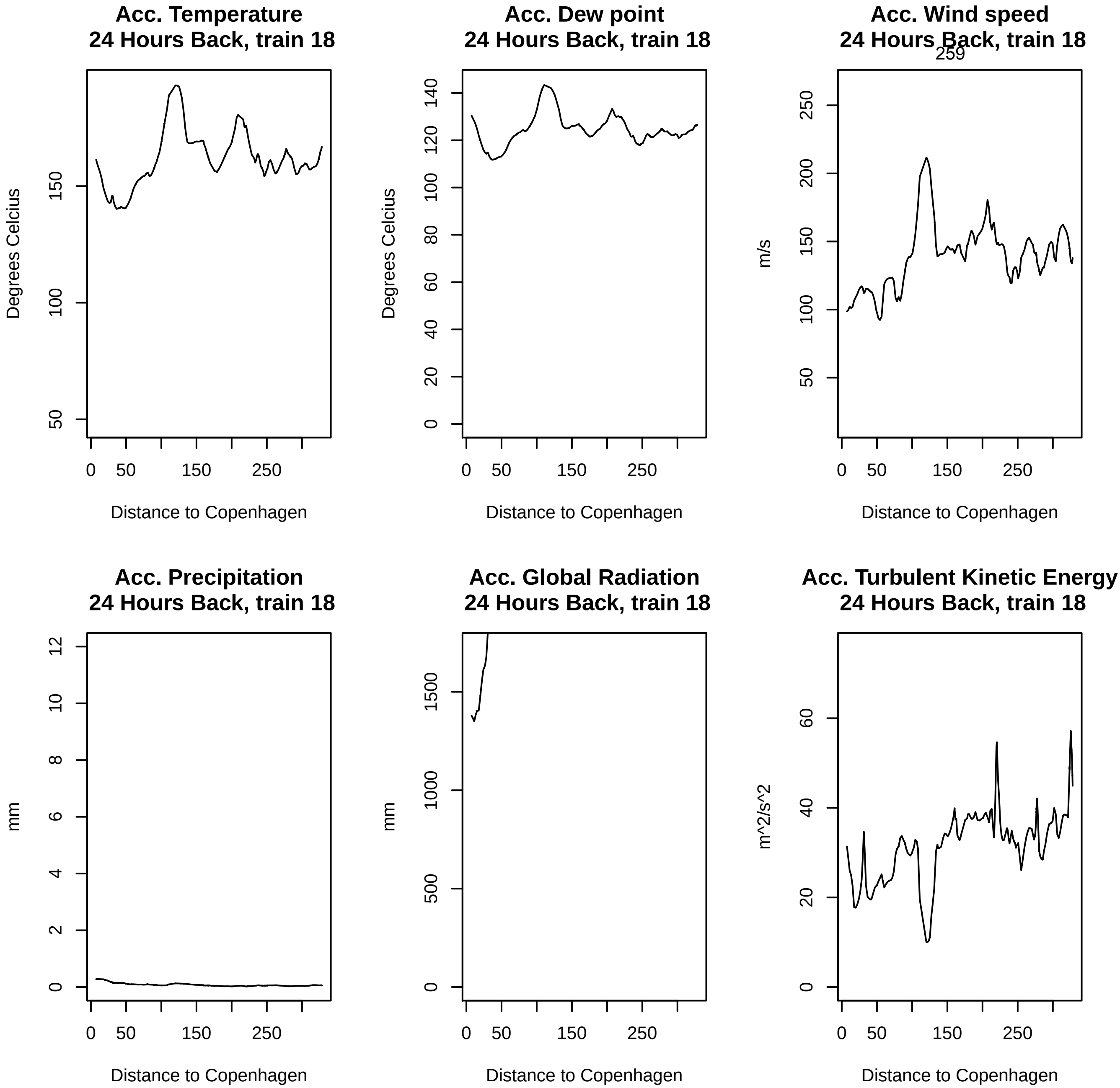
5
10
15
20
0
50
150
250
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 18
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 18
m^2/s^2
Distance to Copenhagen

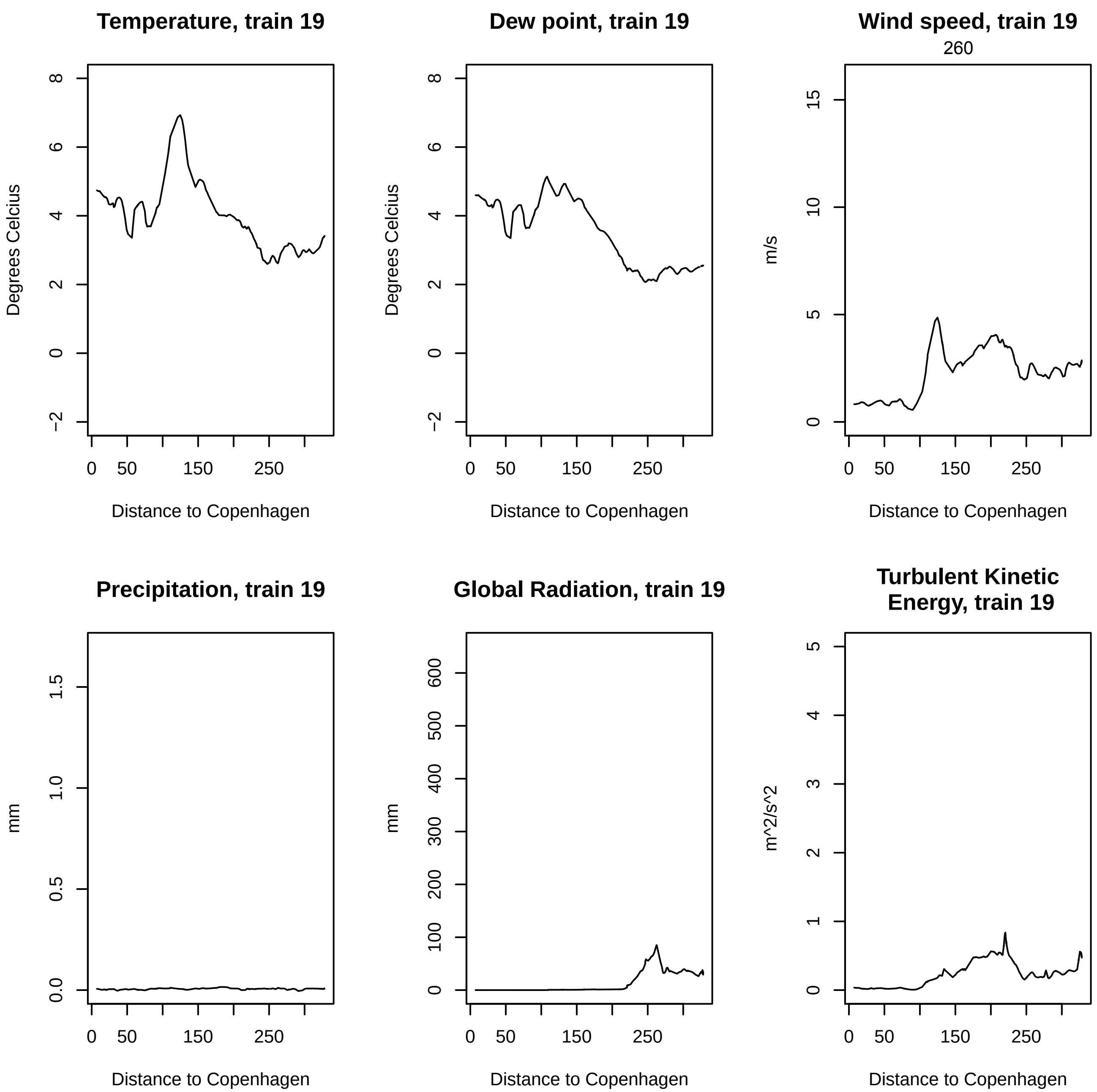

Acc. Temperature
6 Hours Back, train 18
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 18
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 18
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 18
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 18
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 18
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 18
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 18
m^2/s^2
Distance to Copenhagen

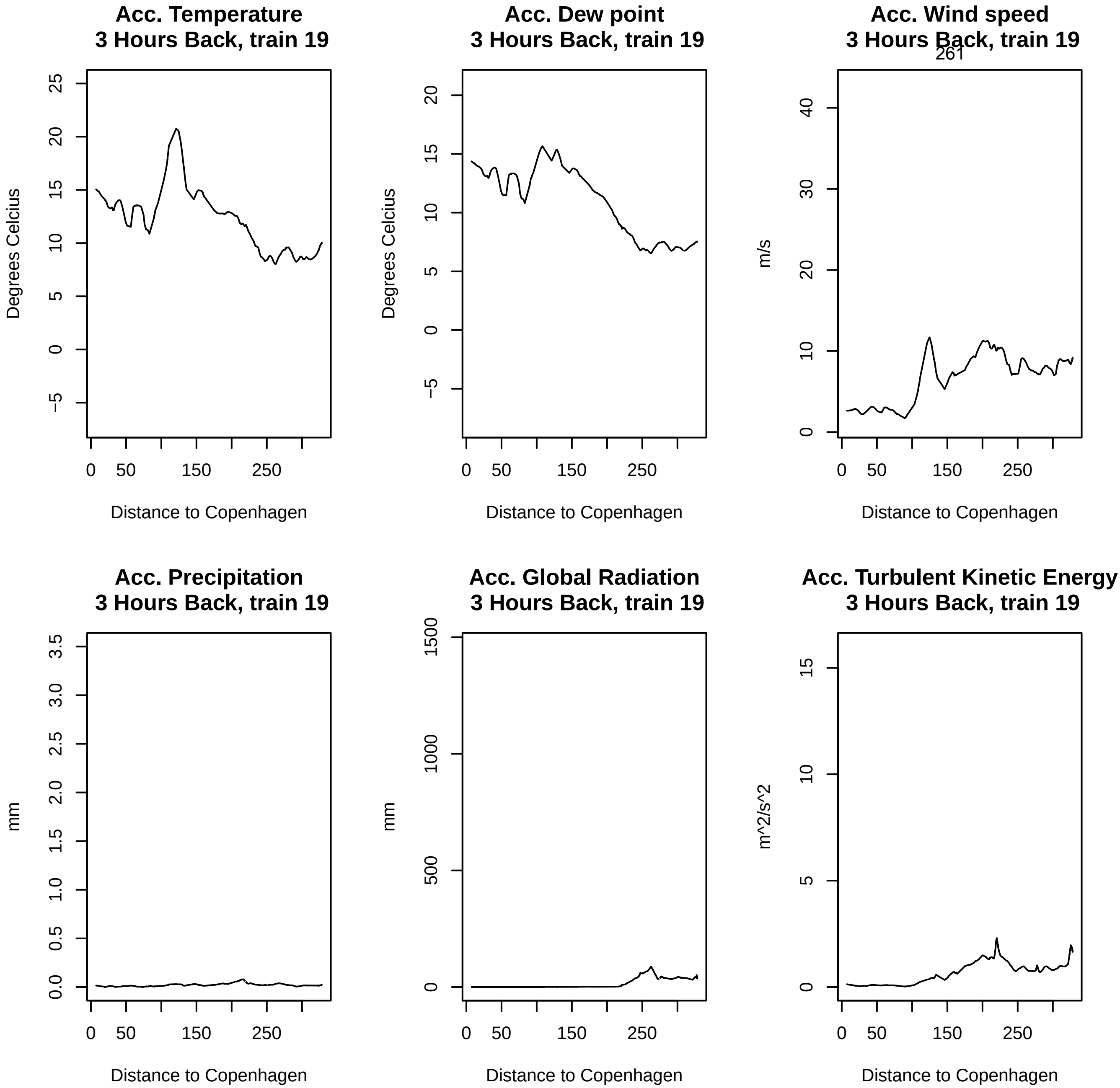

Acc. Temperature
8 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 18
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 18
258
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 18
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 18
m^2/s^2
Distance to Copenhagen

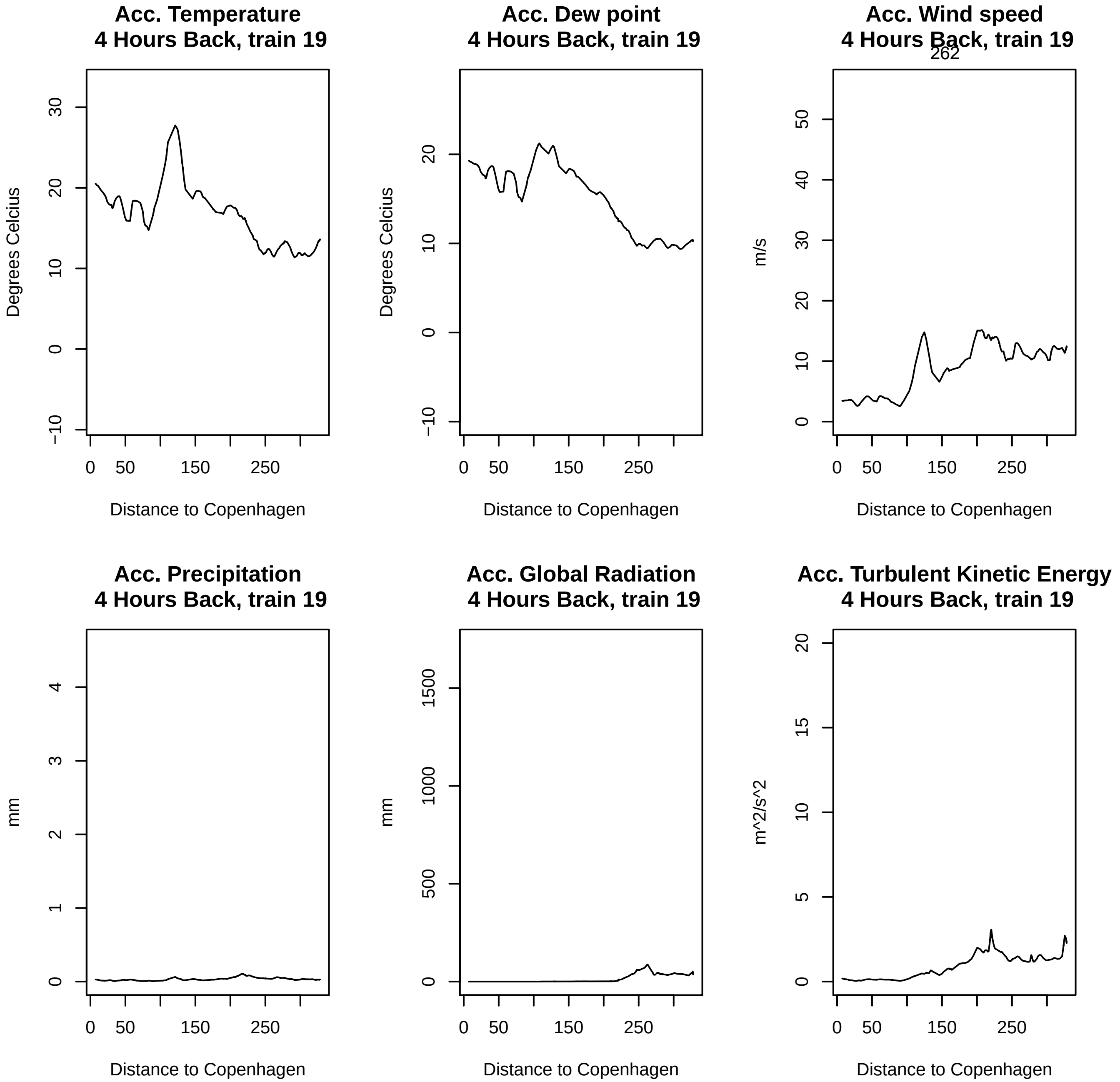


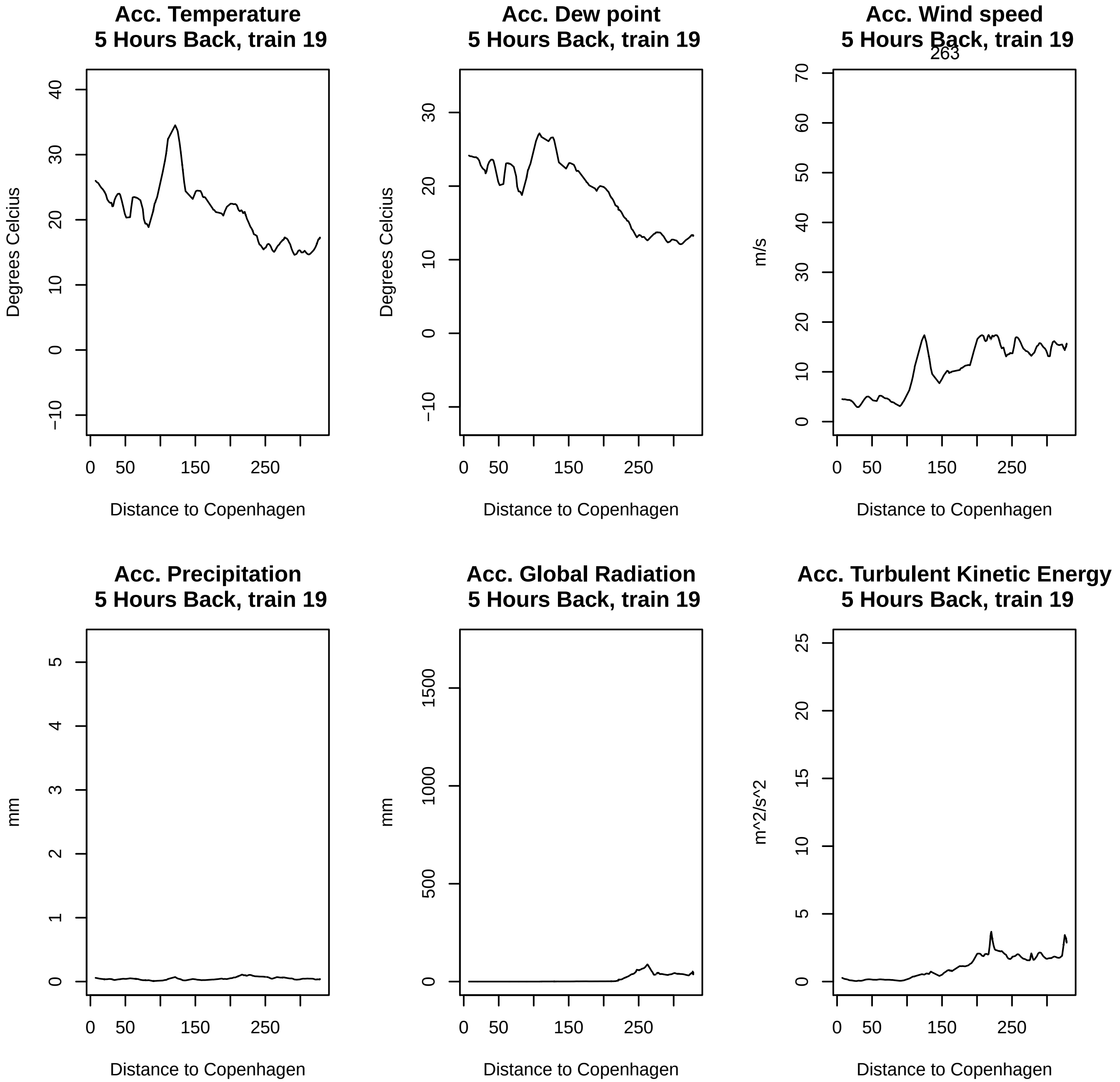
Acc. Temperature
24 Hours Back, train 18
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 18
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 18
259
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 18
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 18
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 18
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

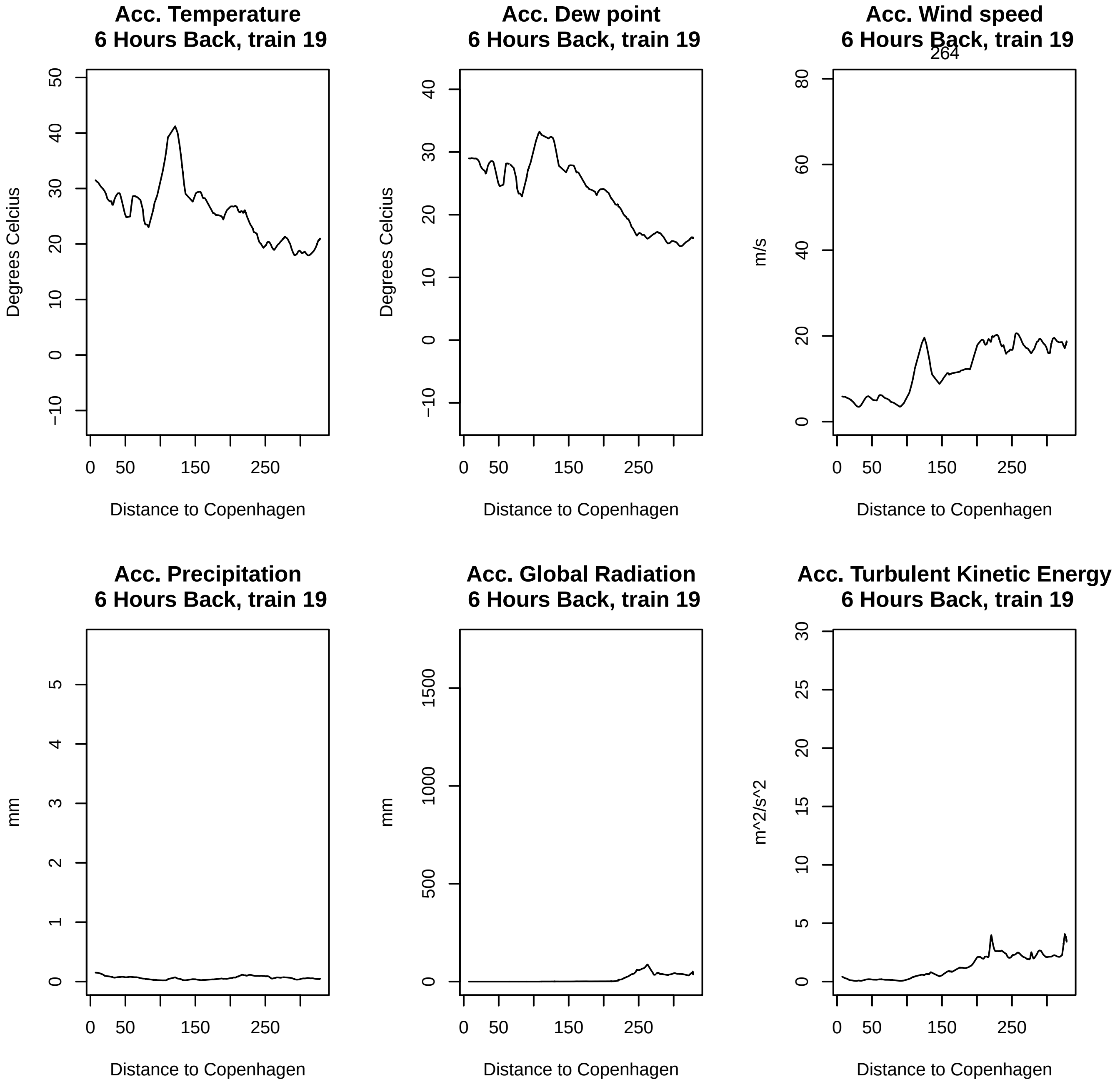


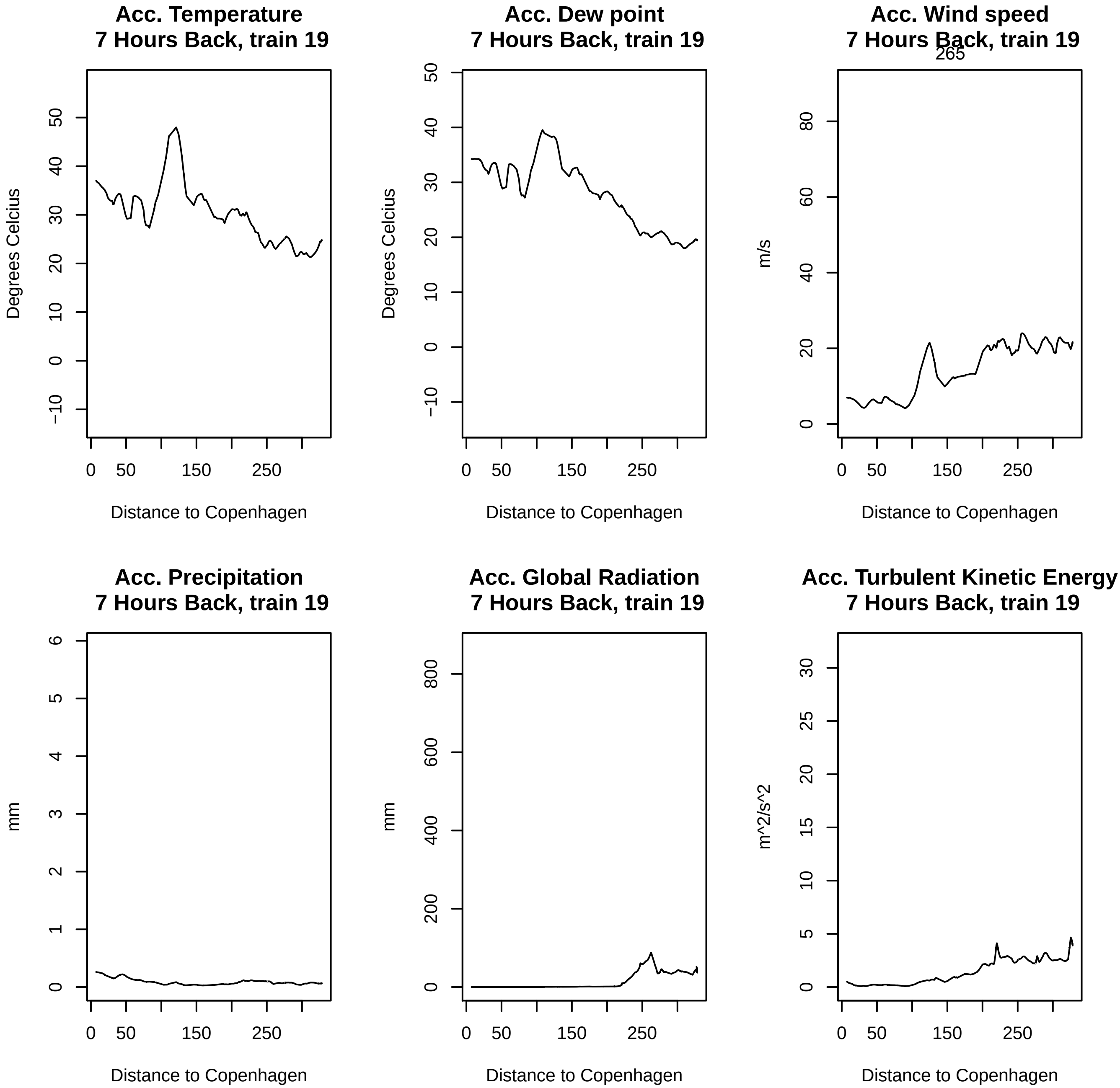
Temperature, train 19
Degrees Celcius
Distance to Copenhagen
Dew point, train 19
Degrees Celcius
Distance to Copenhagen
Wind speed, train 19
260
m/s
Distance to Copenhagen
Precipitation, train 19
mm
Distance to Copenhagen
Global Radiation, train 19
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 19
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 19
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 19
m^2/s^2
Distance to Copenhagen

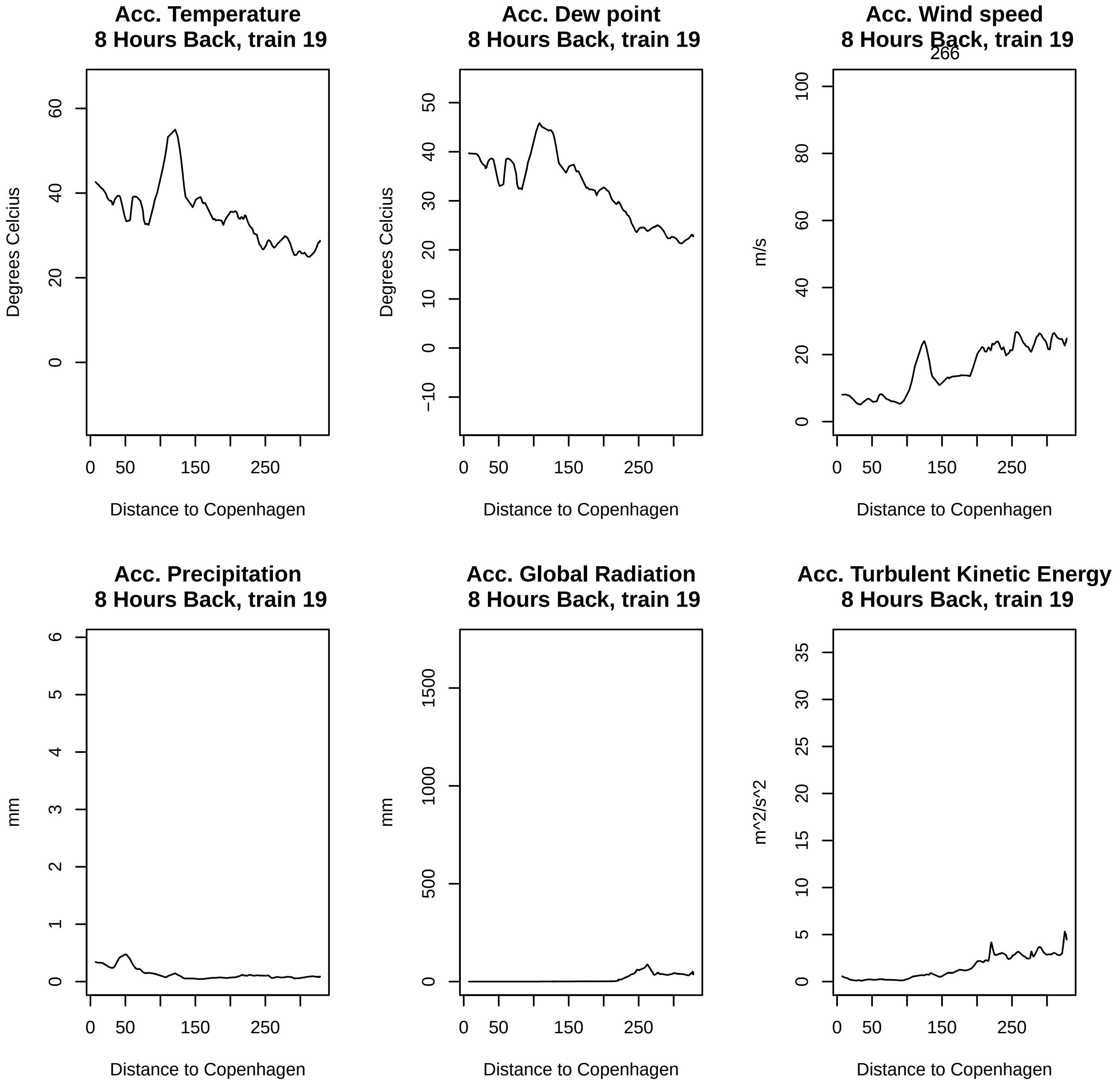

Acc. Temperature
4 Hours Back, train 19
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
0
50
150
250
Acc. Dew point
4 Hours Back, train 19
Degrees Celcius
−10
0
10
20
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 19
m/s
0
10
20
30
40
50
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 19
mm
0
1
2
3
4
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 19
mm
0
500
1000
1500
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 19
m^2/s^2
0
5
10
15
20
Distance to Copenhagen

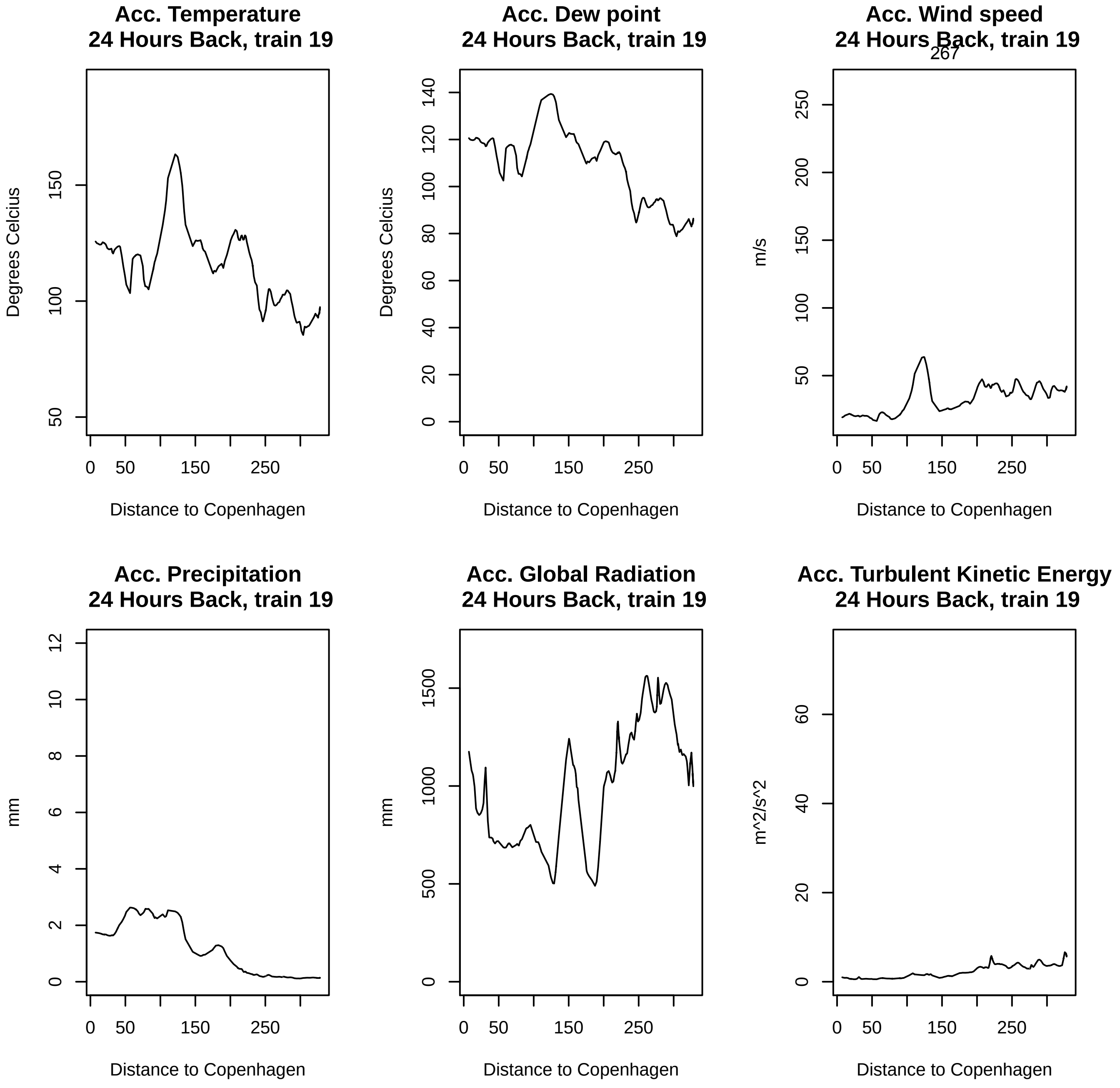

Acc. Temperature
5 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 19
263
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 19
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 19
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 19
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 19
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 19
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 19
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 19
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

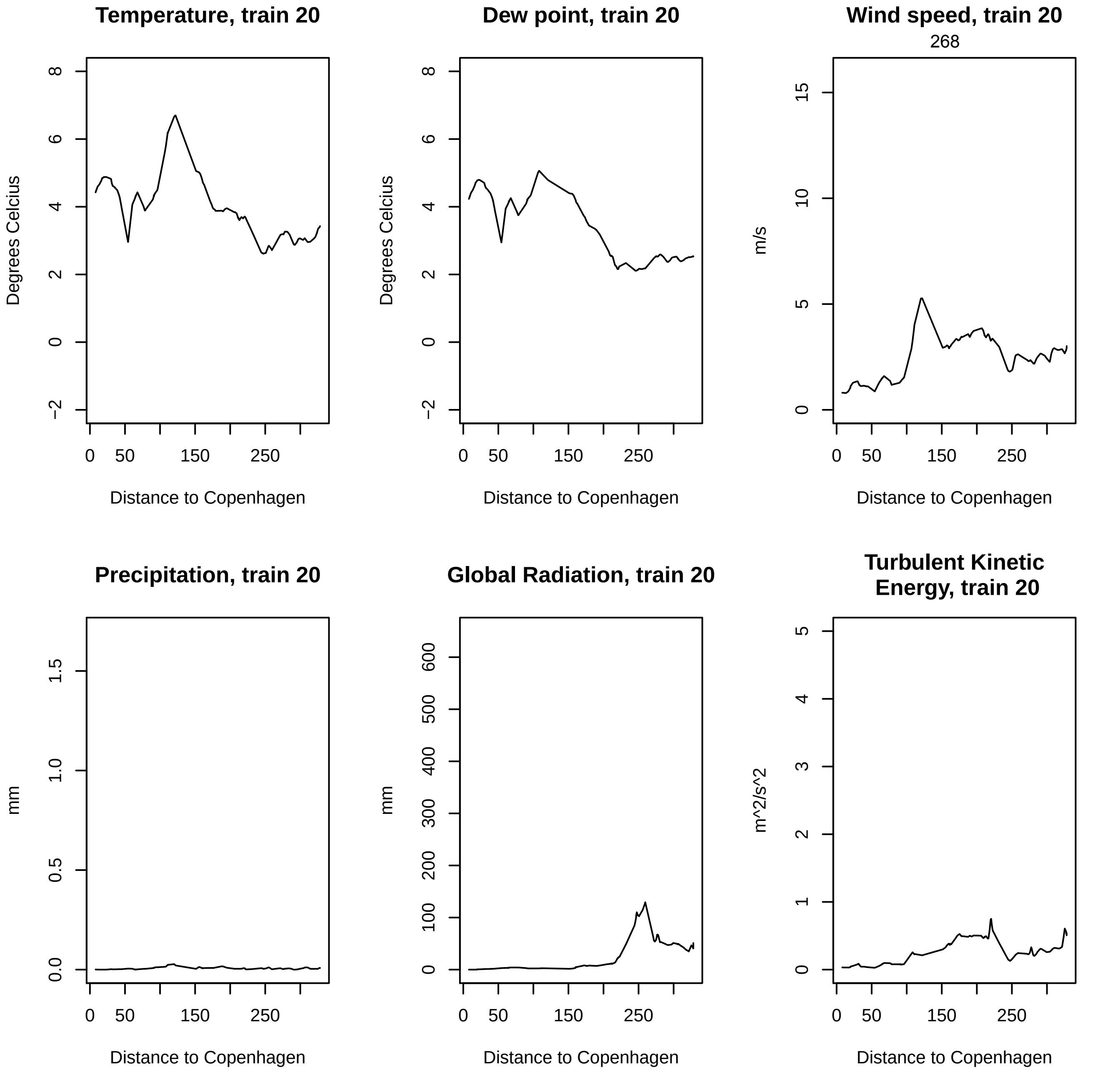


Acc. Temperature
7 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 19
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 19
m^2/s^2
Distance to Copenhagen

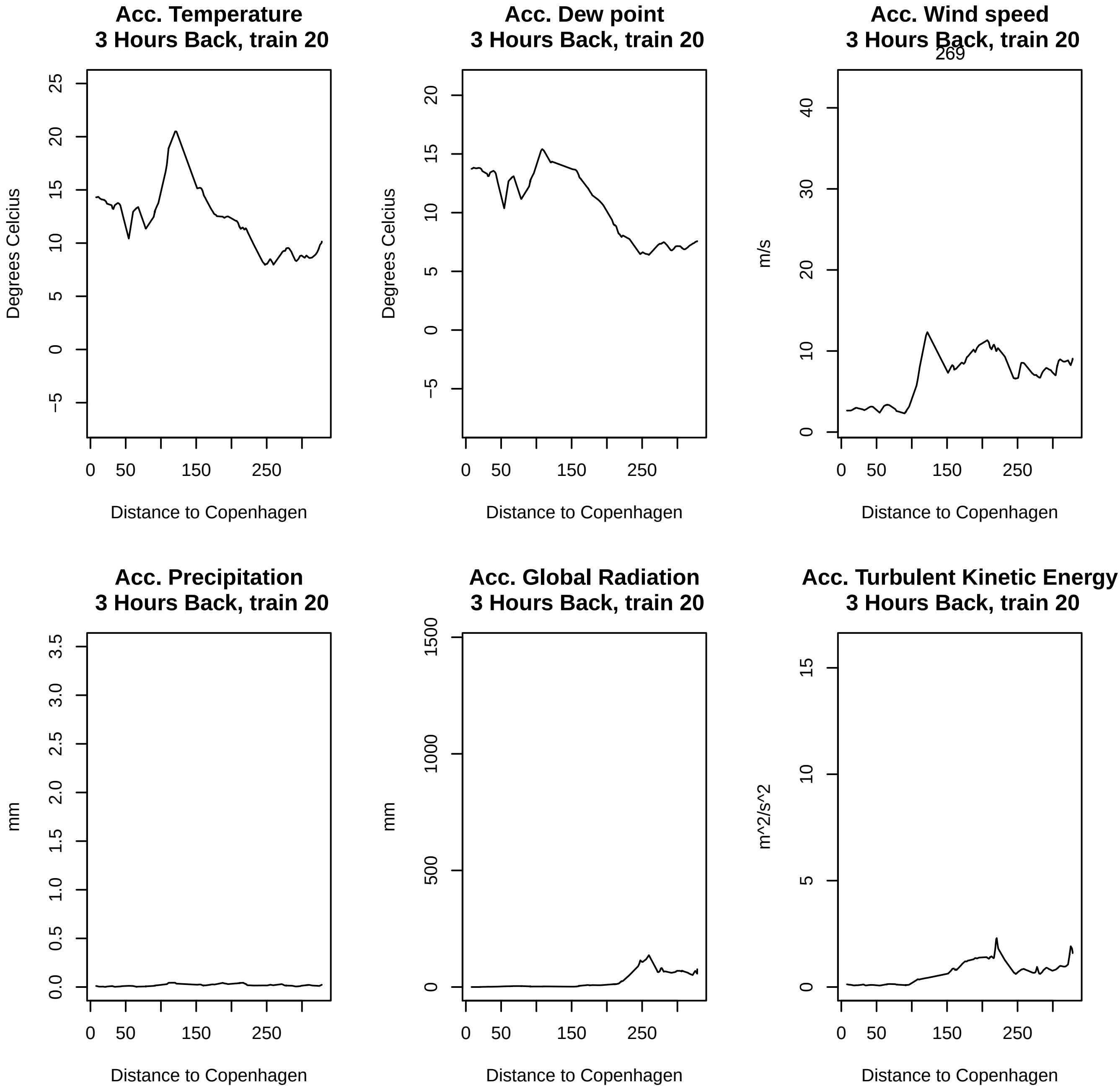

Acc. Temperature
8 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 19
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 19
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 19
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 19
m^2/s^2
Distance to Copenhagen

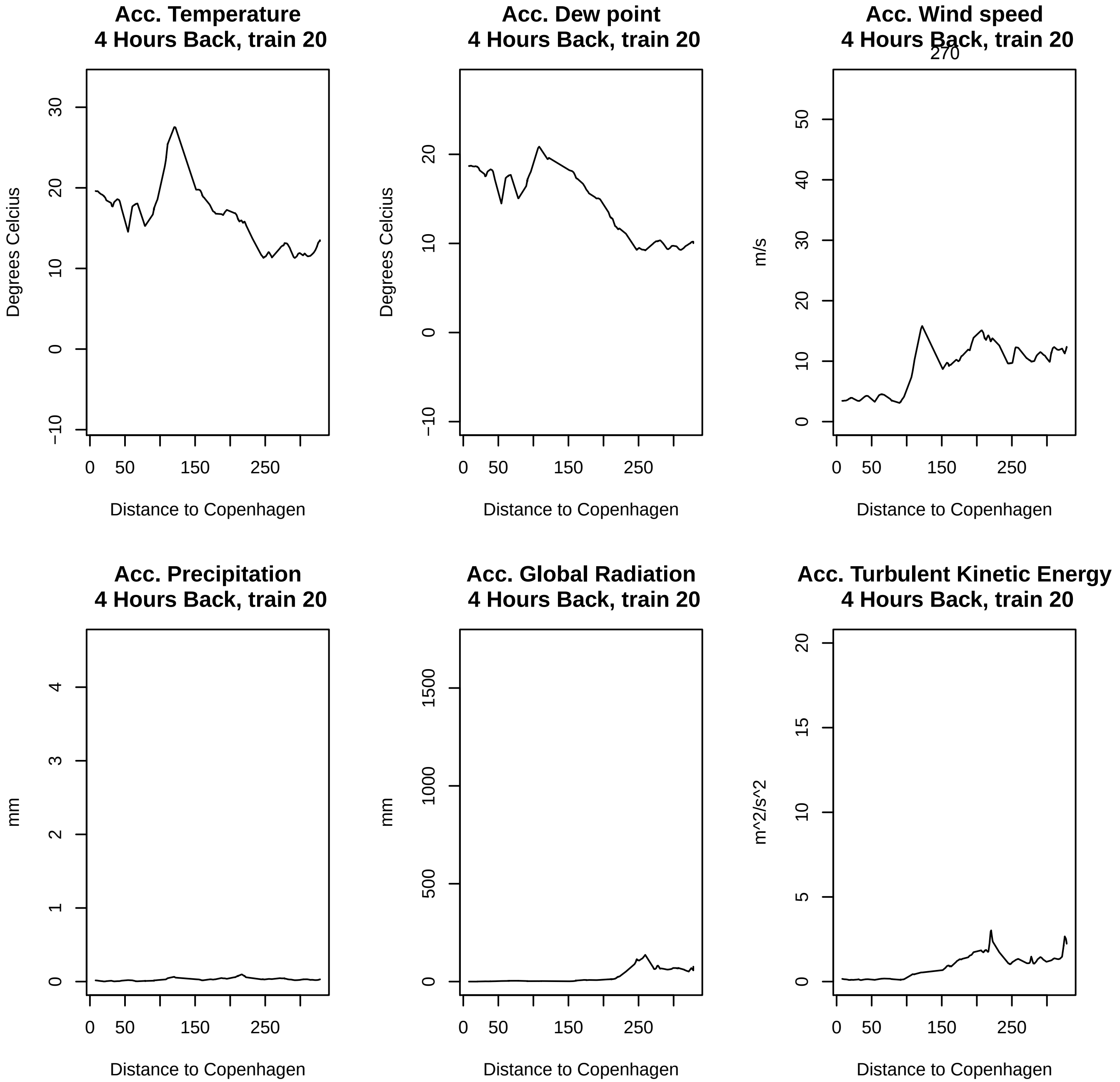


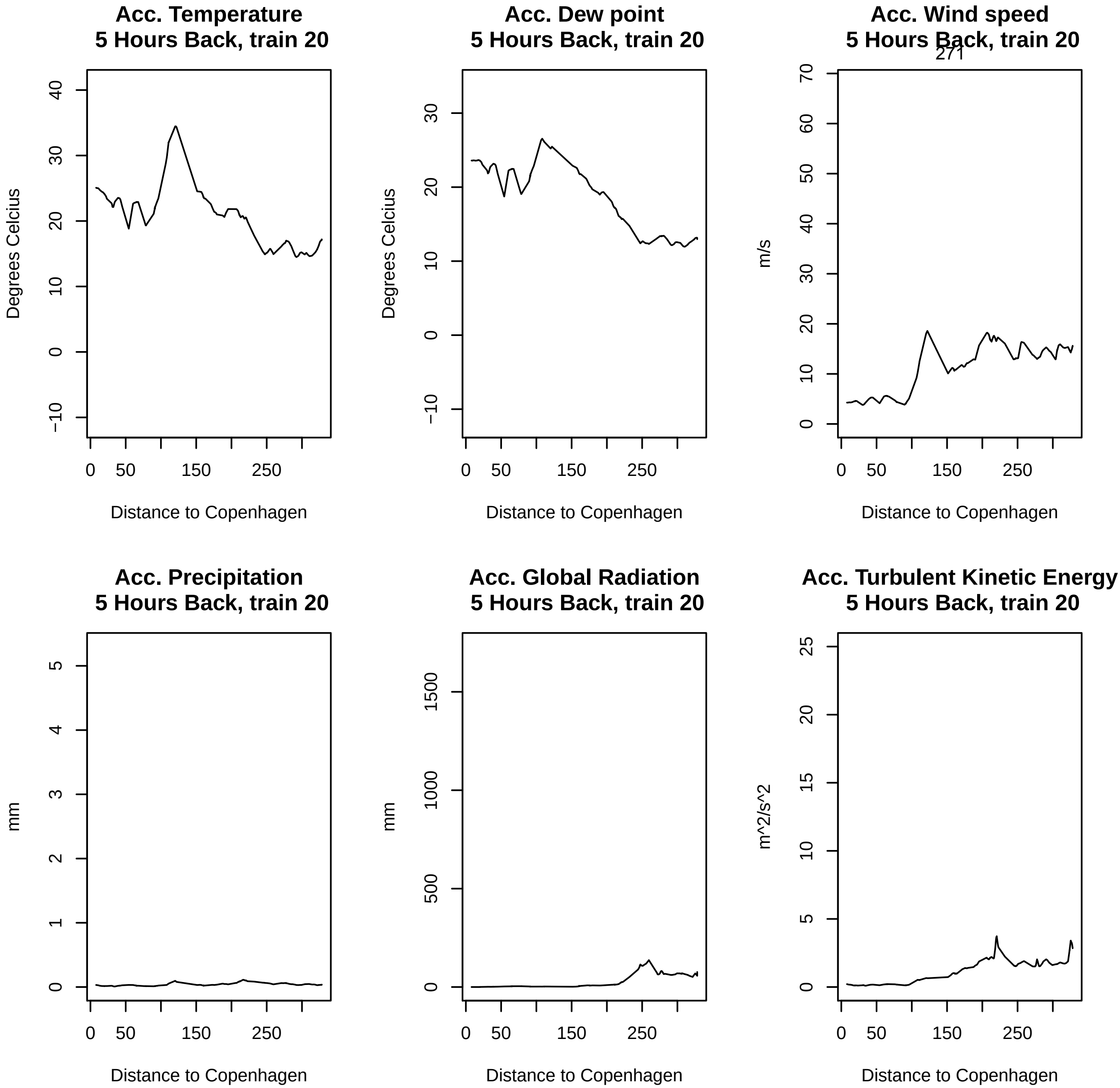
Acc. Temperature
24 Hours Back, train 19
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 19
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 19
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 19
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 19
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 19
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

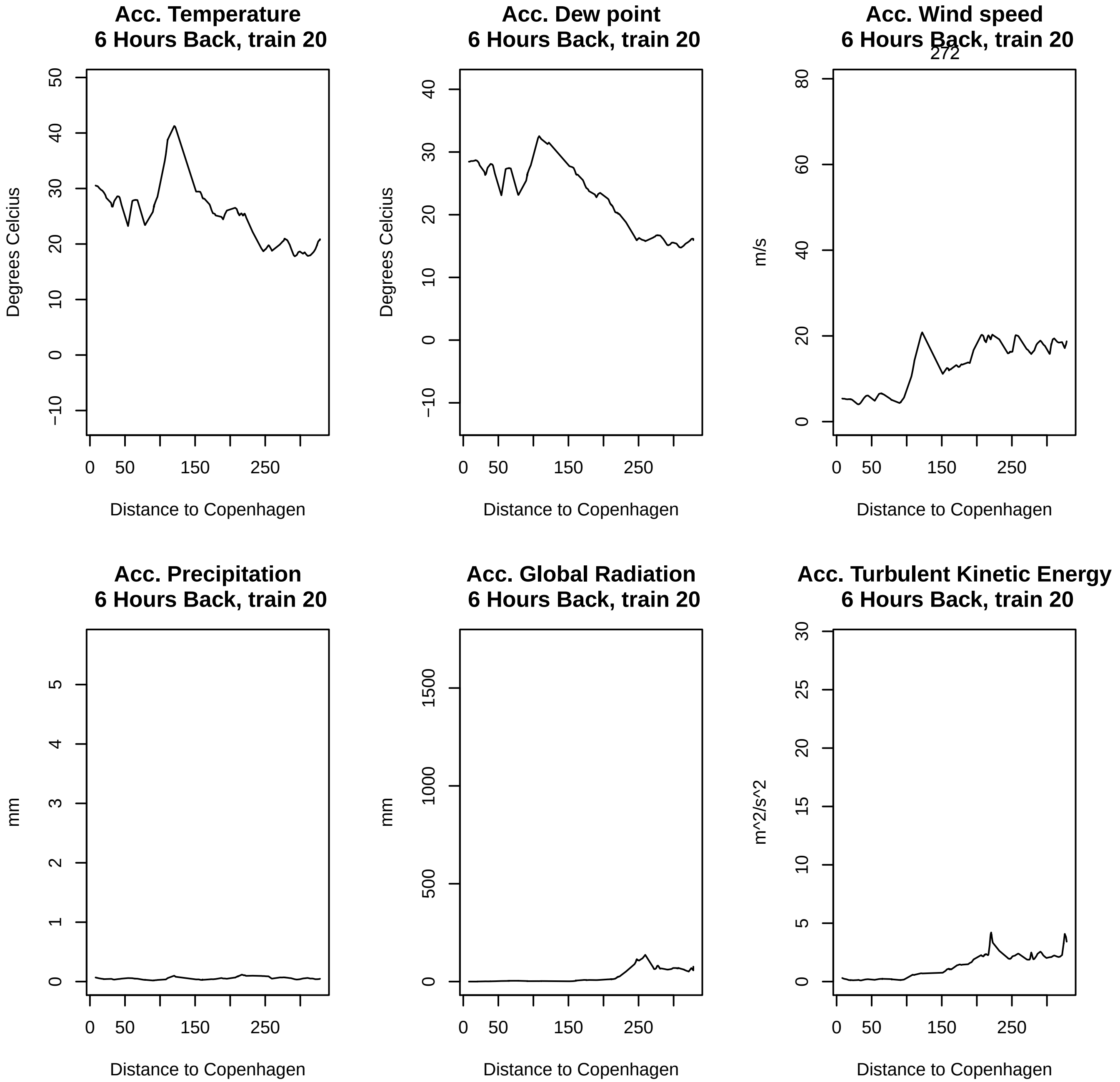


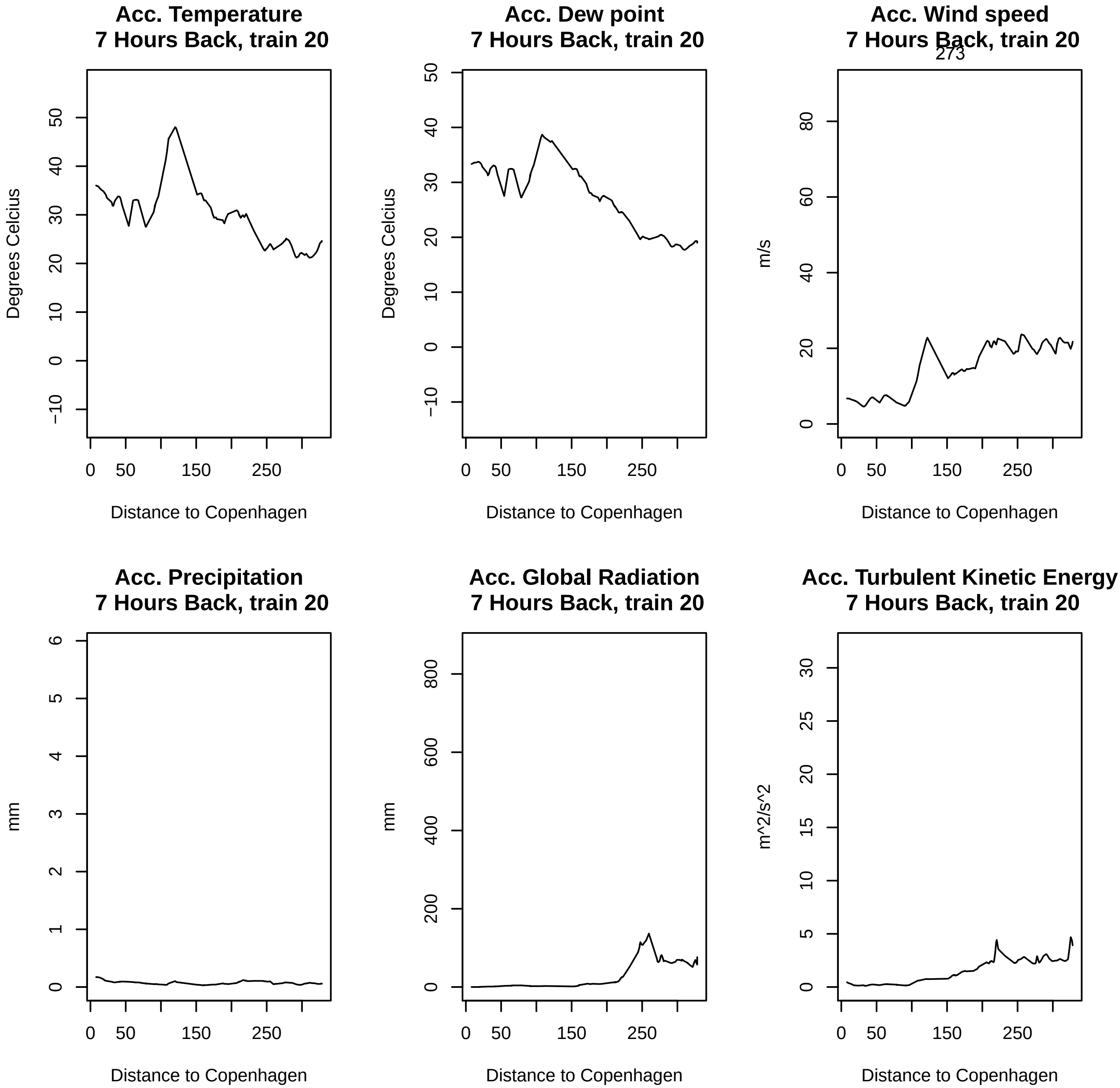
Temperature, train 20
Degrees Celcius
Distance to Copenhagen
Dew point, train 20
Degrees Celcius
Distance to Copenhagen
Wind speed, train 20
m/s
Distance to Copenhagen
Precipitation, train 20
mm
Distance to Copenhagen
Global Radiation, train 20
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 20
m^2/s^2
Distance to Copenhagen

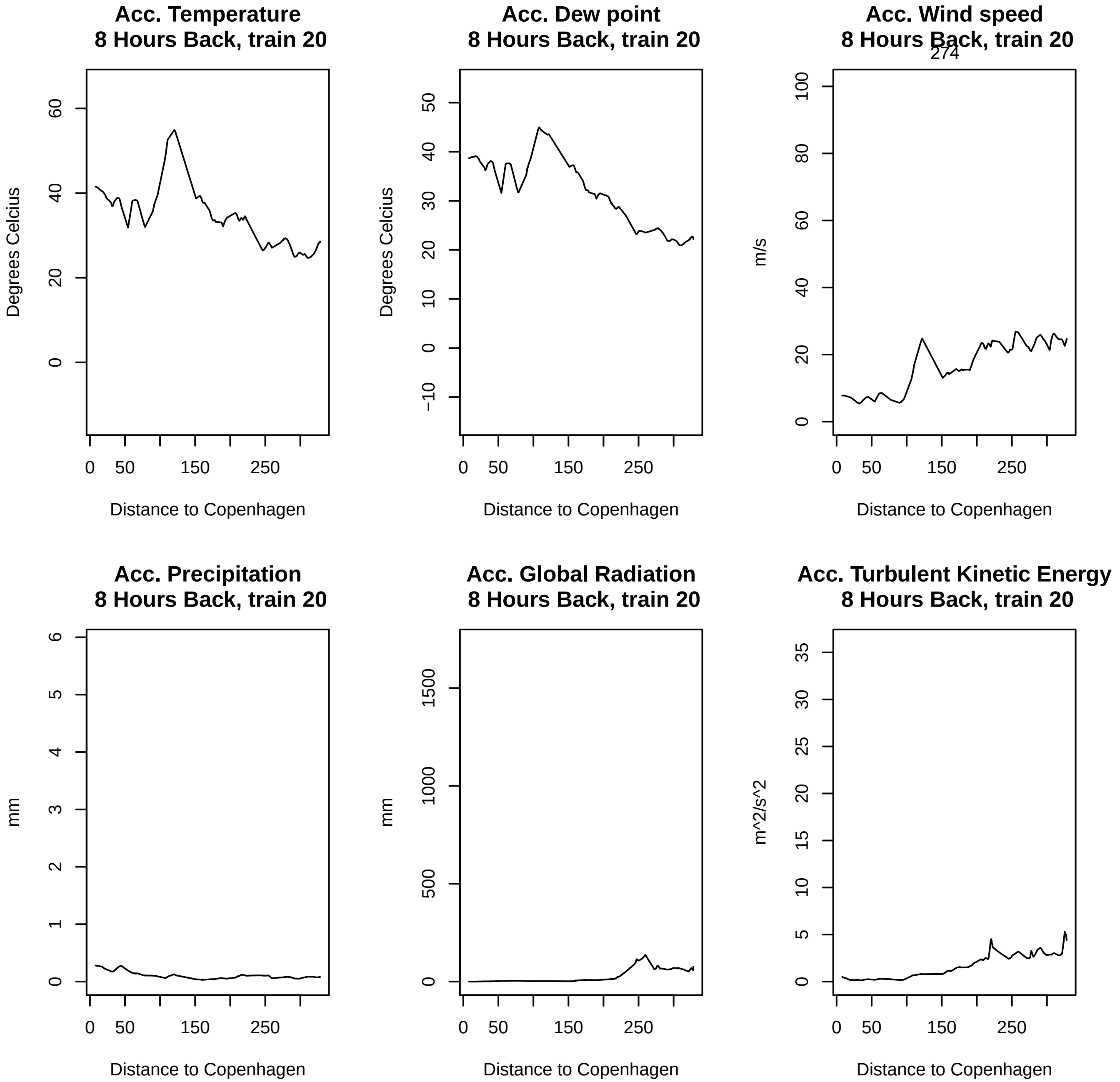

Acc. Temperature
3 Hours Back, train 20
Degrees Celcius
−5
0
5
10
15
20
25
Distance to Copenhagen
0
50
150
250
Acc. Dew point
3 Hours Back, train 20
Degrees Celcius
−5
0
5
10
15
20
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
3 Hours Back, train 20
m/s
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
3 Hours Back, train 20
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
3 Hours Back, train 20
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
3 Hours Back, train 20
m^2/s^2
0
5
10
15
Distance to Copenhagen
0
50
150
250


Acc. Temperature
4 Hours Back, train 20
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 20
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 20
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 20
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 20
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 20
m^2/s^2
0
5
10
15
20
0
50
150
250
Distance to Copenhagen

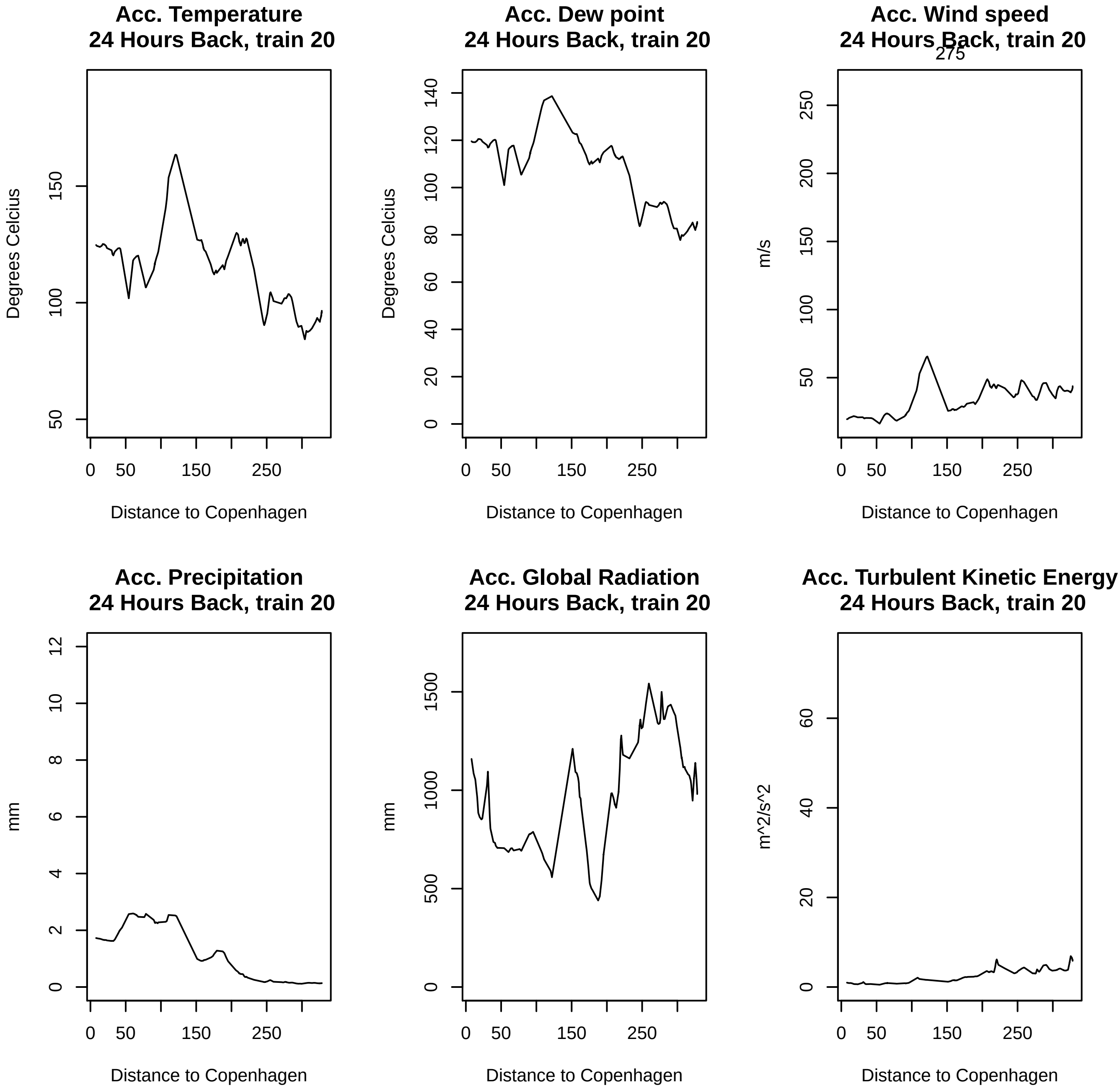

Acc. Temperature
5 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 20
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 20
m^2/s^2
Distance to Copenhagen

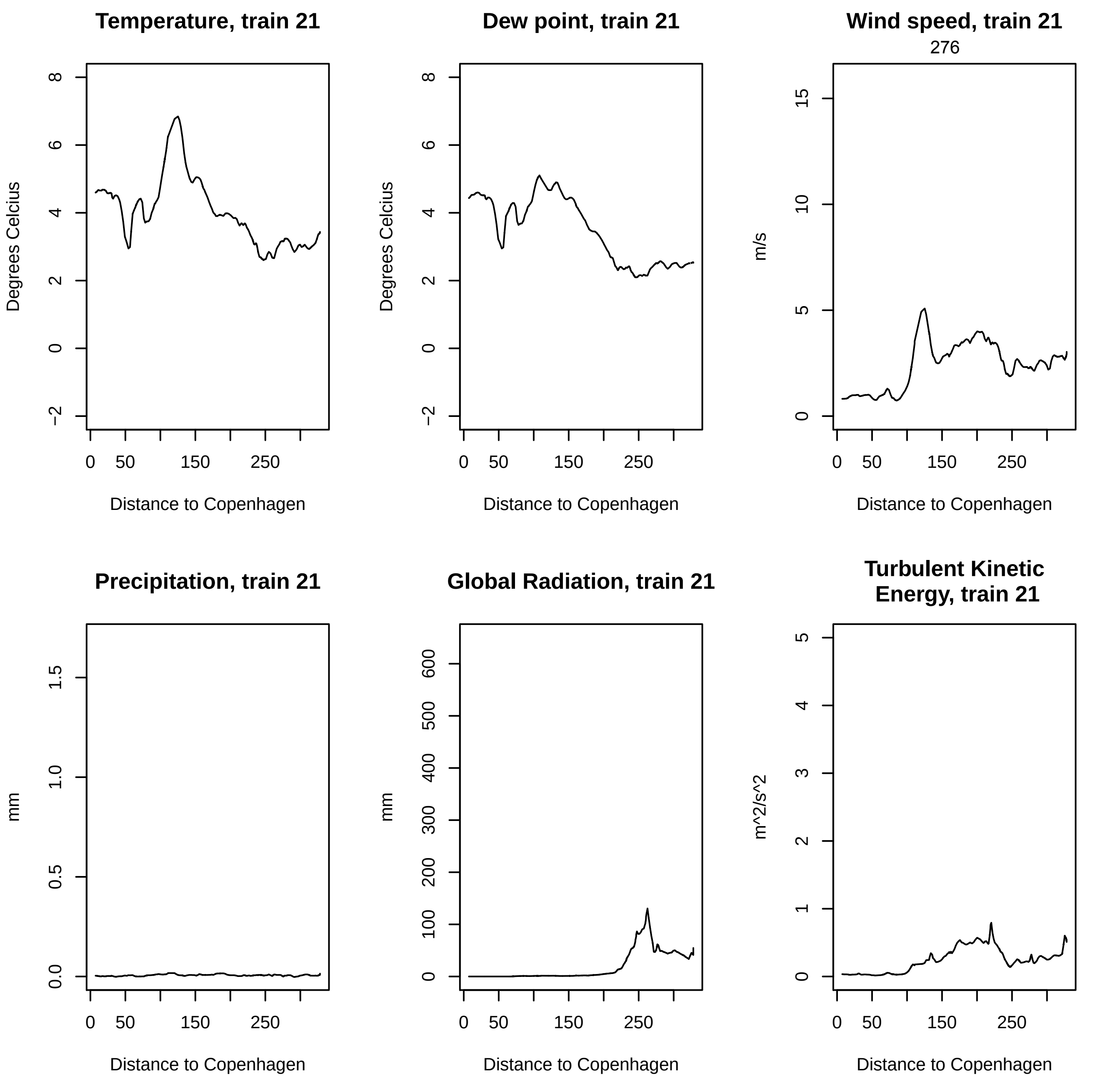

Acc. Temperature
6 Hours Back, train 20
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 20
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 20
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 20
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 20
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 20
m^2/s^2
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 20
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 20
m^2/s^2
Distance to Copenhagen

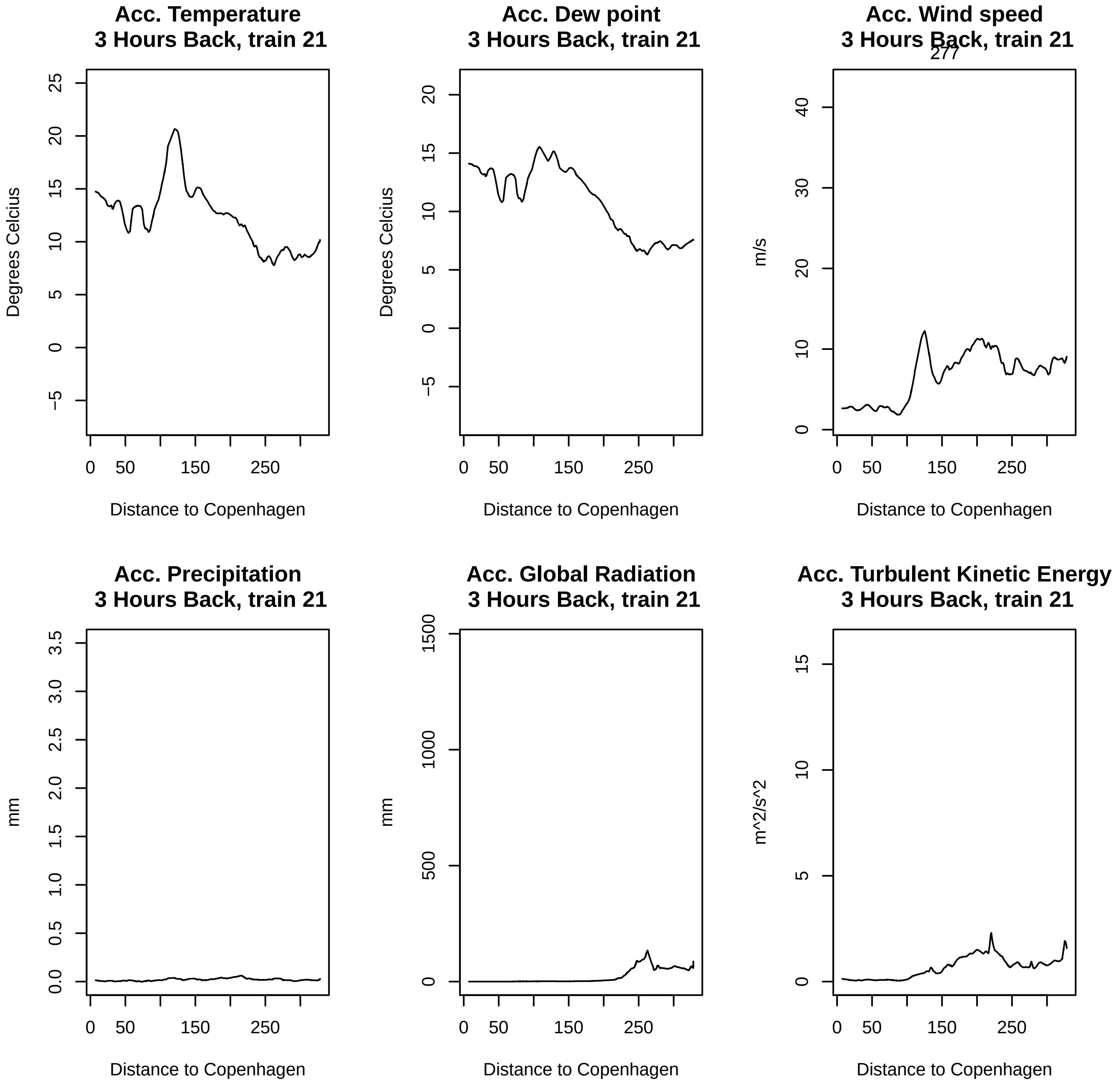


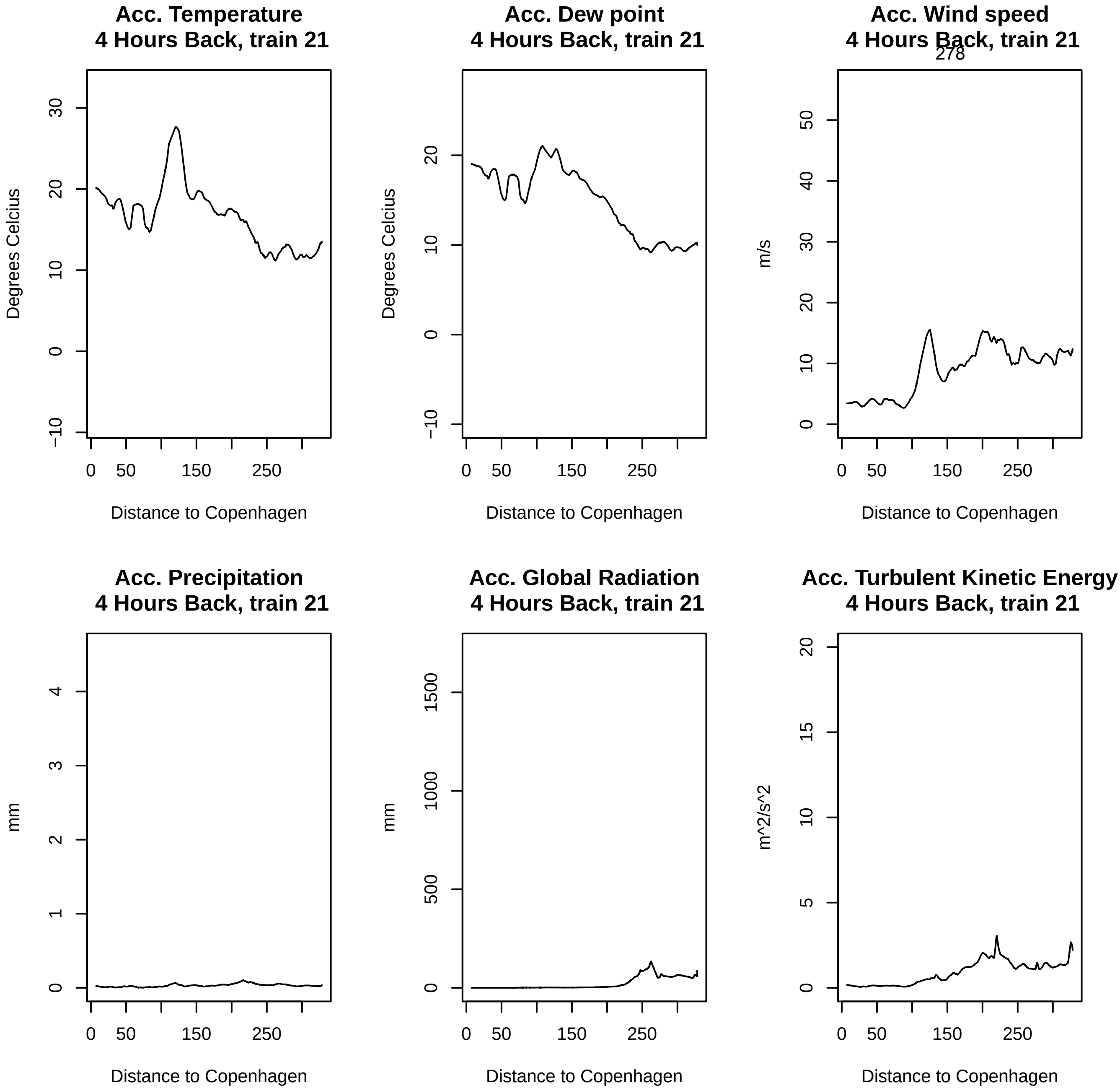
Acc. Temperature
8 Hours Back, train 20
Degrees Celcius
0
20
40
60
Distance to Copenhagen
0
50
150
250
Acc. Dew point
8 Hours Back, train 20
Degrees Celcius
−10
0
10
20
30
40
50
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
8 Hours Back, train 20
m/s
0
20
40
60
80
100
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
8 Hours Back, train 20
mm
0
1
2
3
4
5
6
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
8 Hours Back, train 20
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
8 Hours Back, train 20
m^2/s^2
0
5
10
15
20
25
30
35
Distance to Copenhagen
0
50
150
250

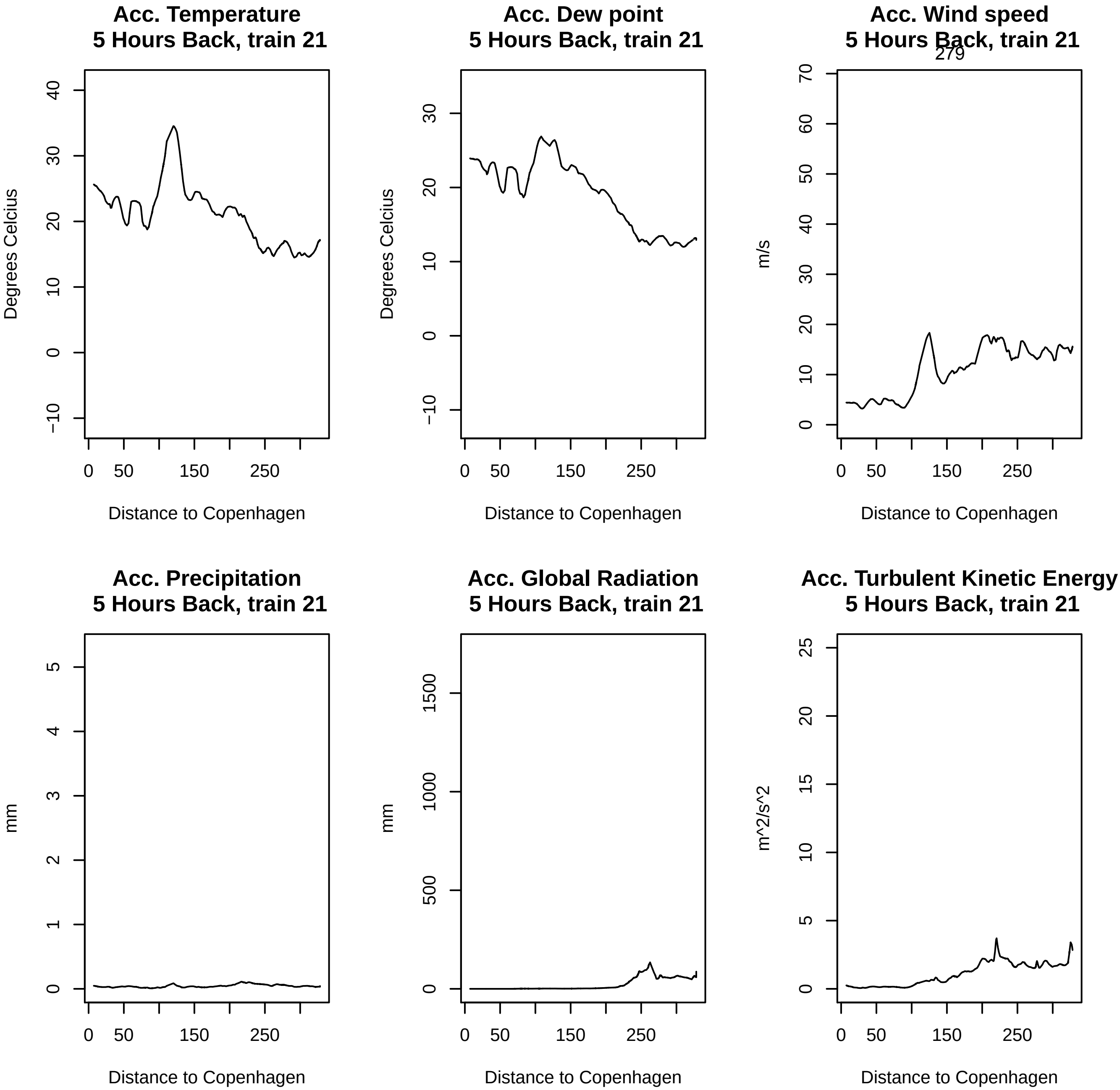

Acc. Temperature
24 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 20
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 20
275
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 20
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 20
m^2/s^2
Distance to Copenhagen

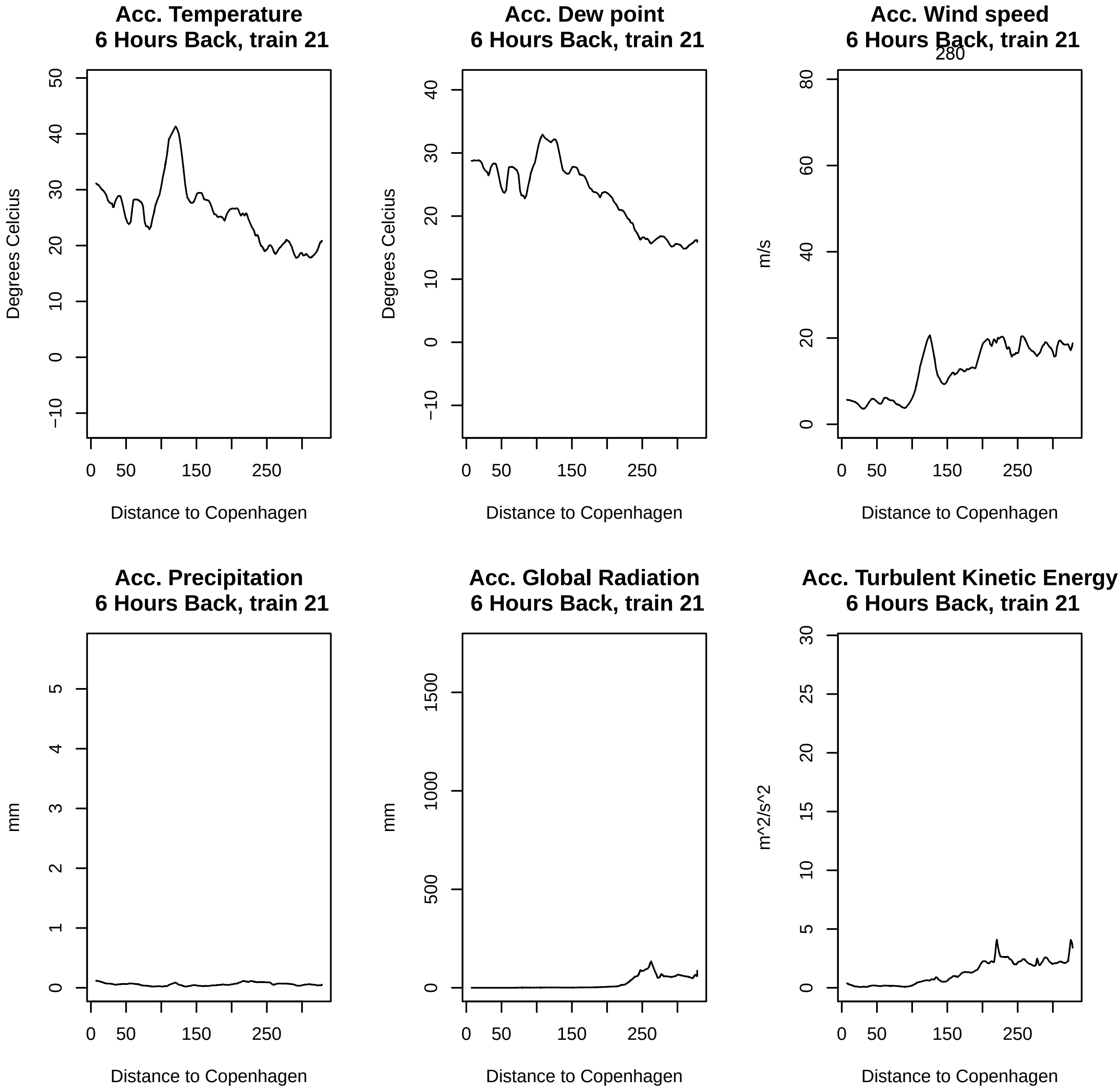


Temperature, train 21
Degrees Celcius
Dew point, train 21
Degrees Celcius
Wind speed, train 21
276
m/s
Precipitation, train 21
mm
Global Radiation, train 21
mm
Turbulent Kinetic Energy, train 21
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 21
Degrees Celcius
−5 0 5 10 15 20 25
0 50 150 250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 21
Degrees Celcius
−5 0 5 10 15 20
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 21
m/s
0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 21
mm
0.0 0.5 1.0 1.5 2.0 2.5 3.0 3.5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 21
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 21
m^2/s^2
0 5 10 15
0 50 150 250
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 21
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 21
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 21
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 21
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 21
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 21
m^2/s^2
0
5
10
15
20
0
50
150
250
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 21
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 21
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 21
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 21
Degrees Celcius
−10
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10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 21
m/s
0
20
40
60
80
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 21
mm
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 21
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 21
m^2/s^2
0
5
10
15
20
25
30
0
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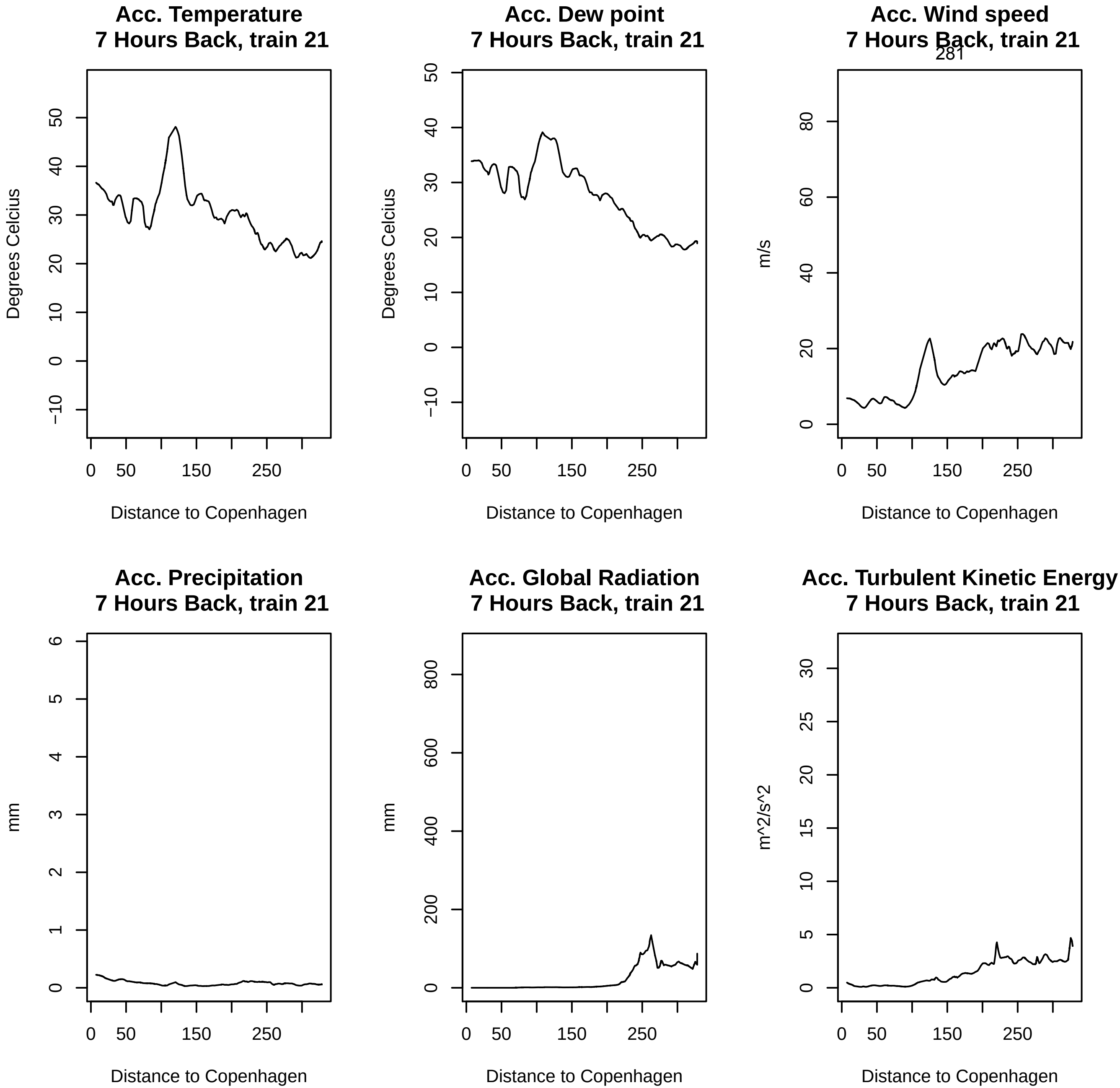
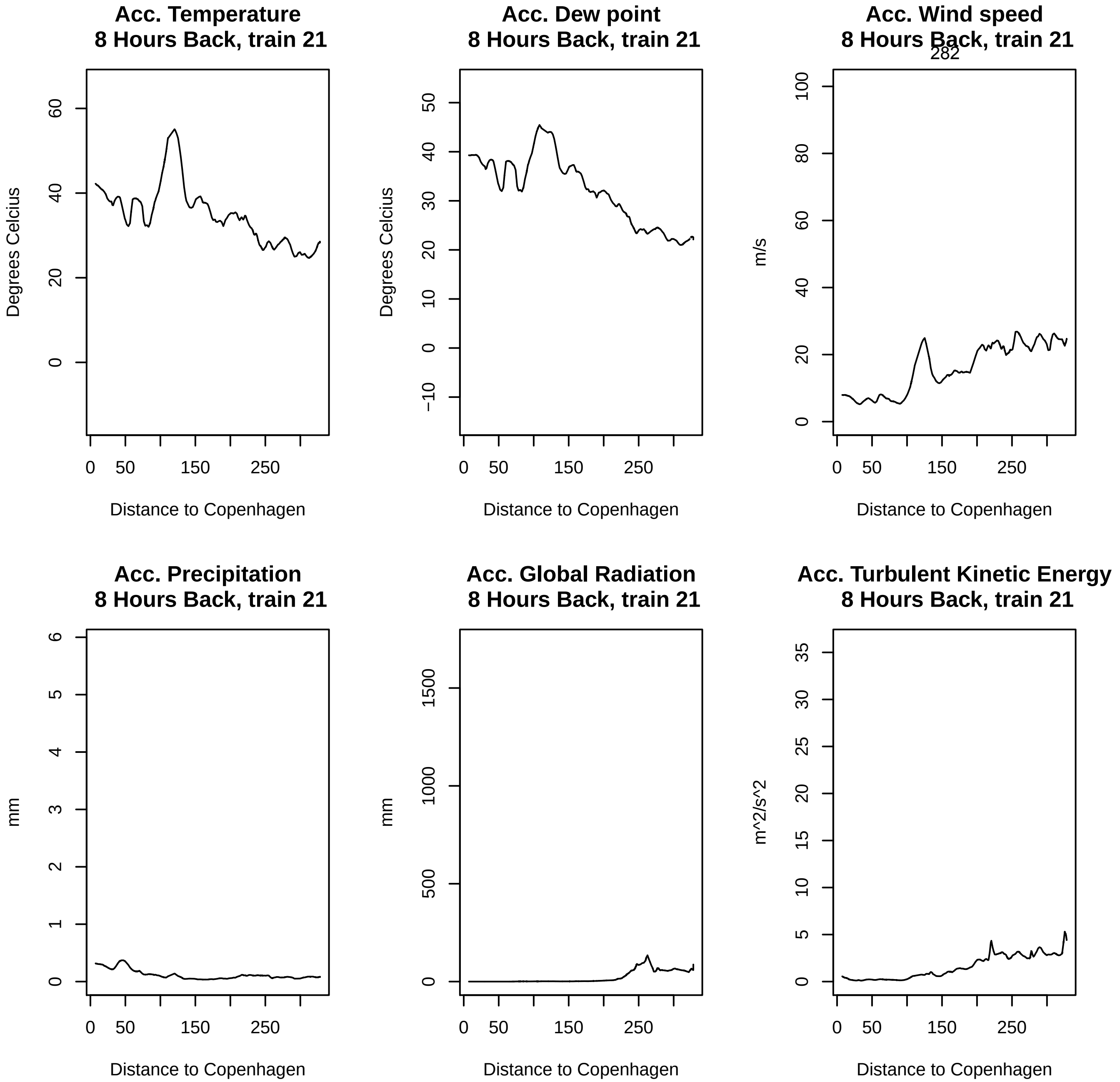
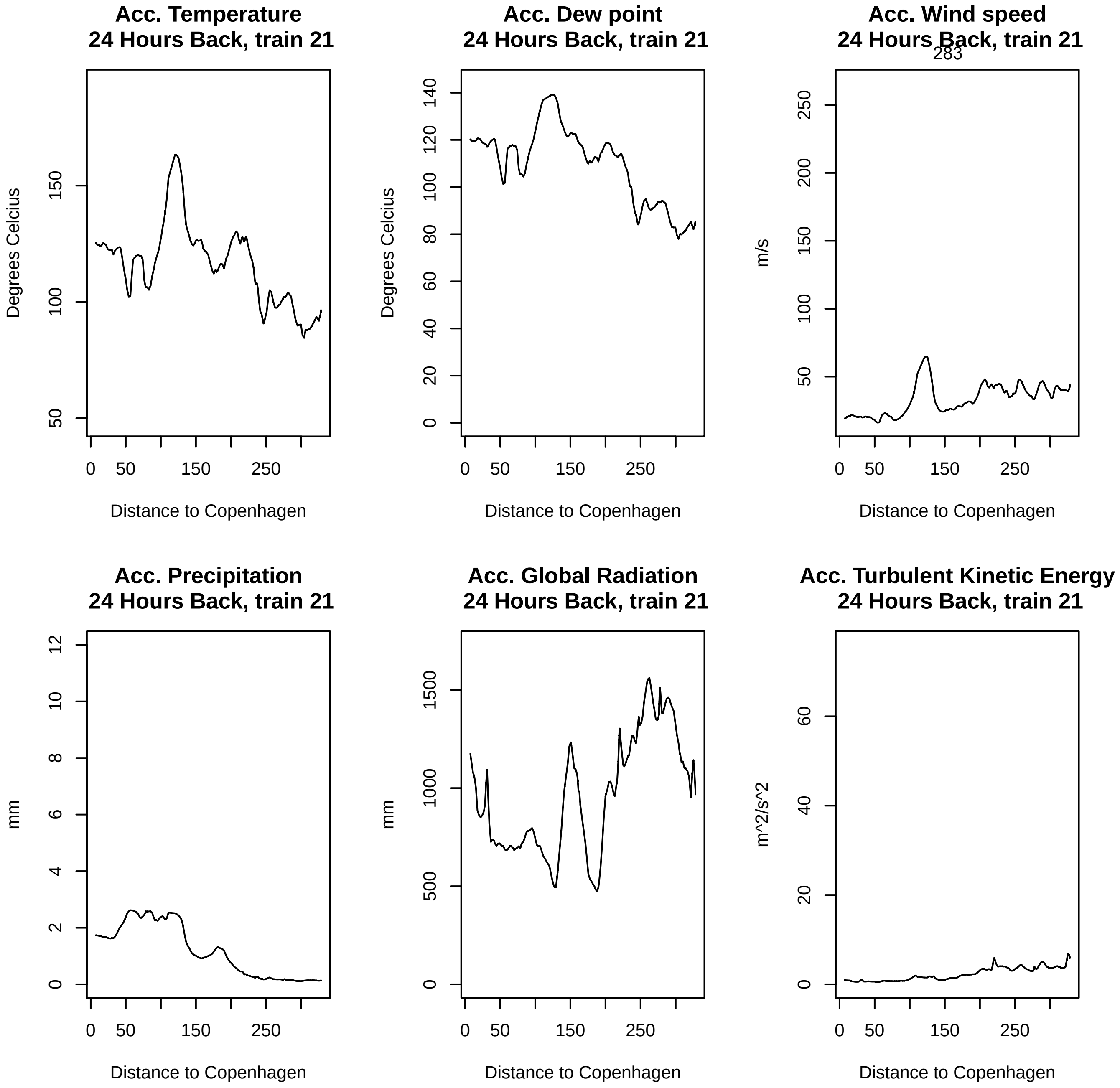
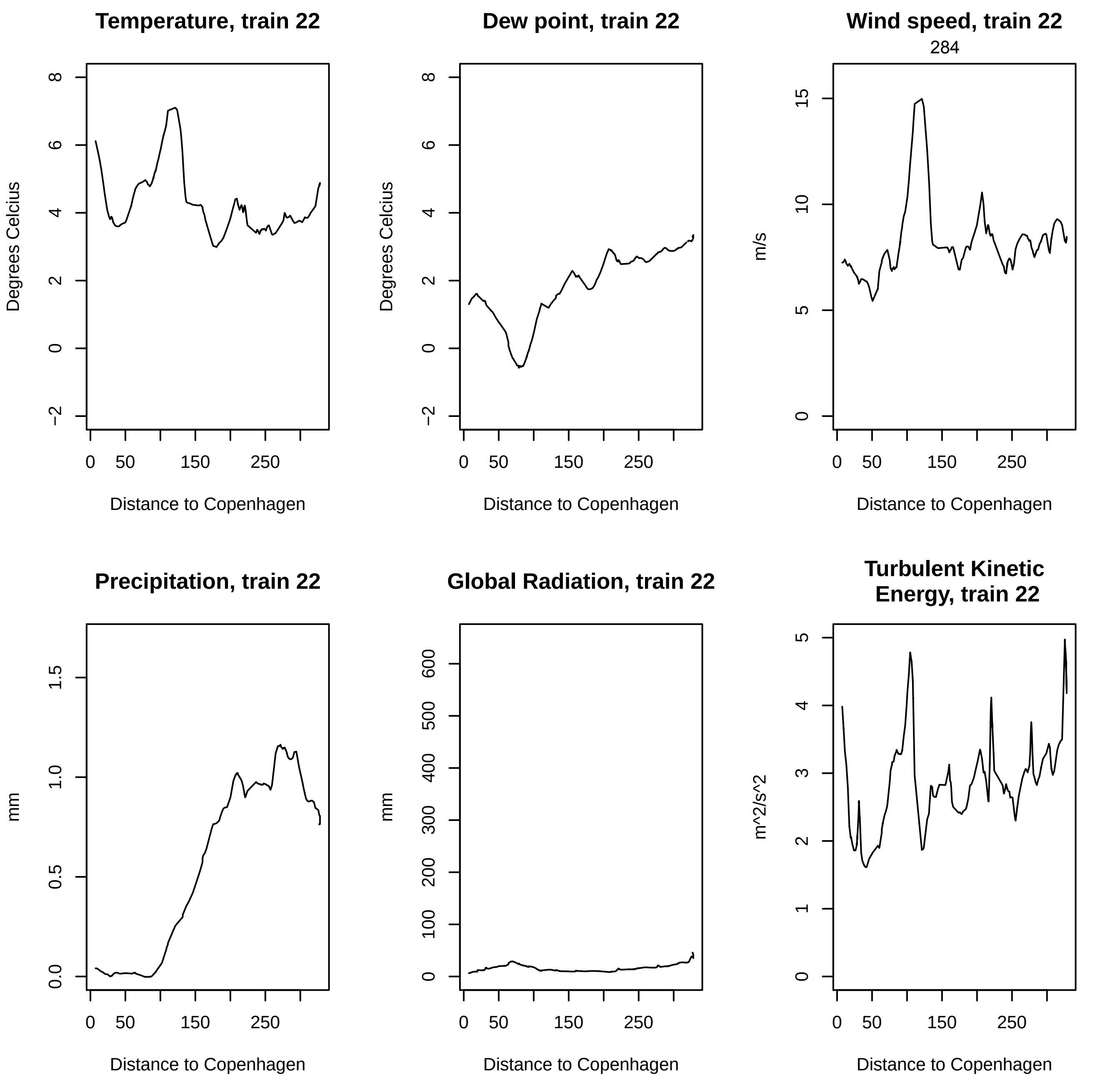
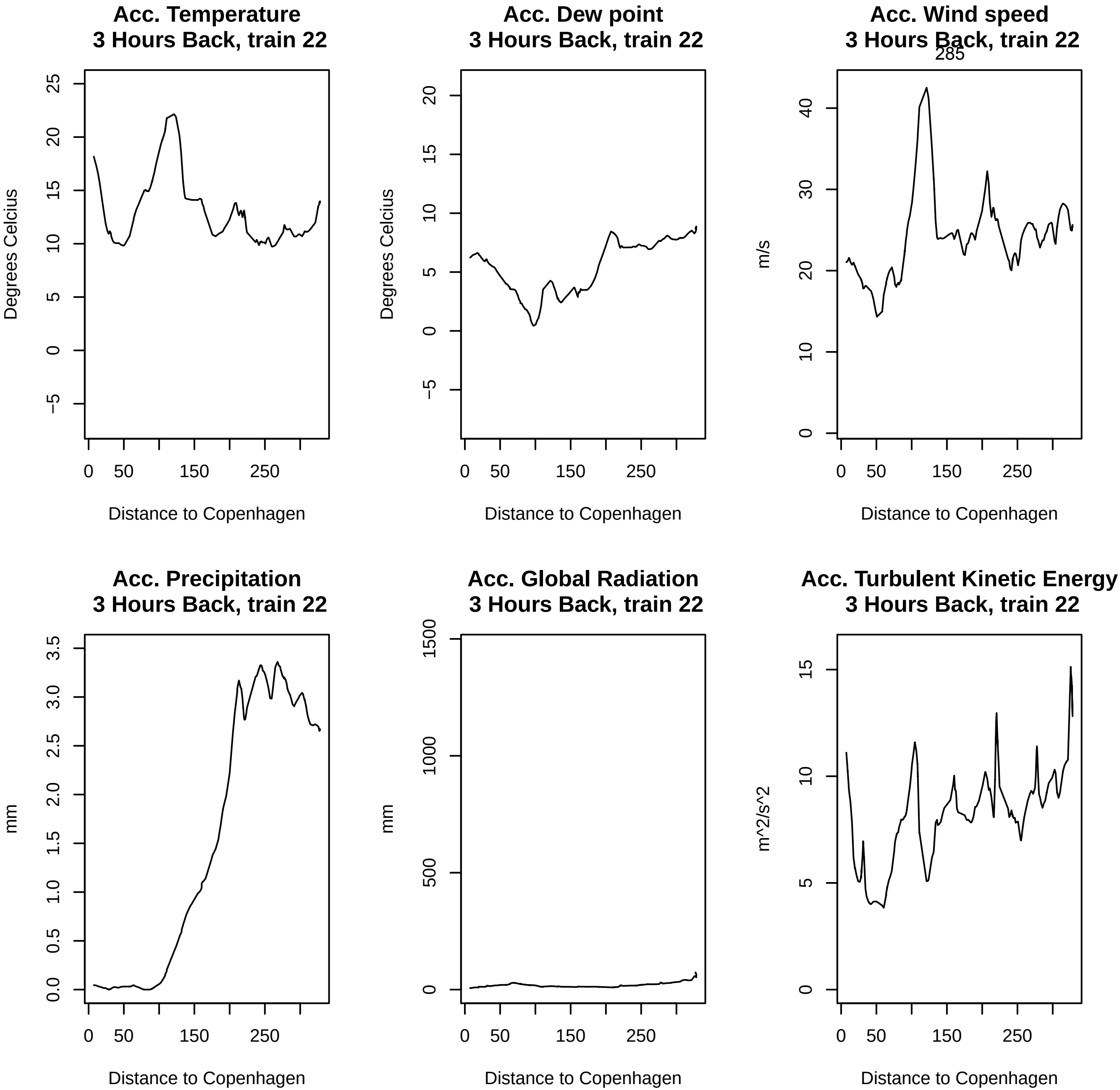
150
250
Distance to Copenhagen

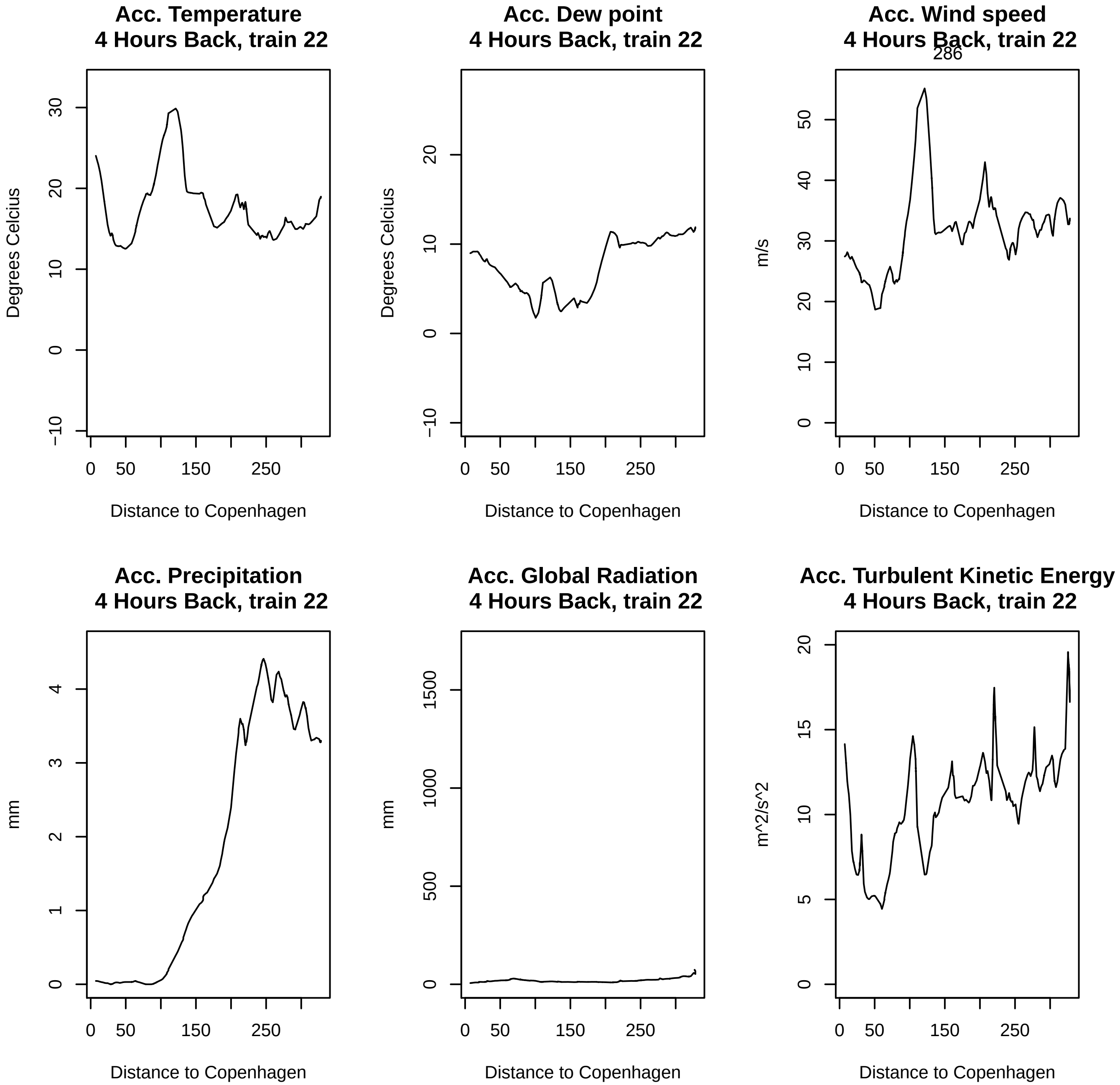

Acc. Temperature
7 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 21
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 21
m^2/s^2
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 21
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 21
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 21
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 21
m^2/s^2
Distance to Copenhagen

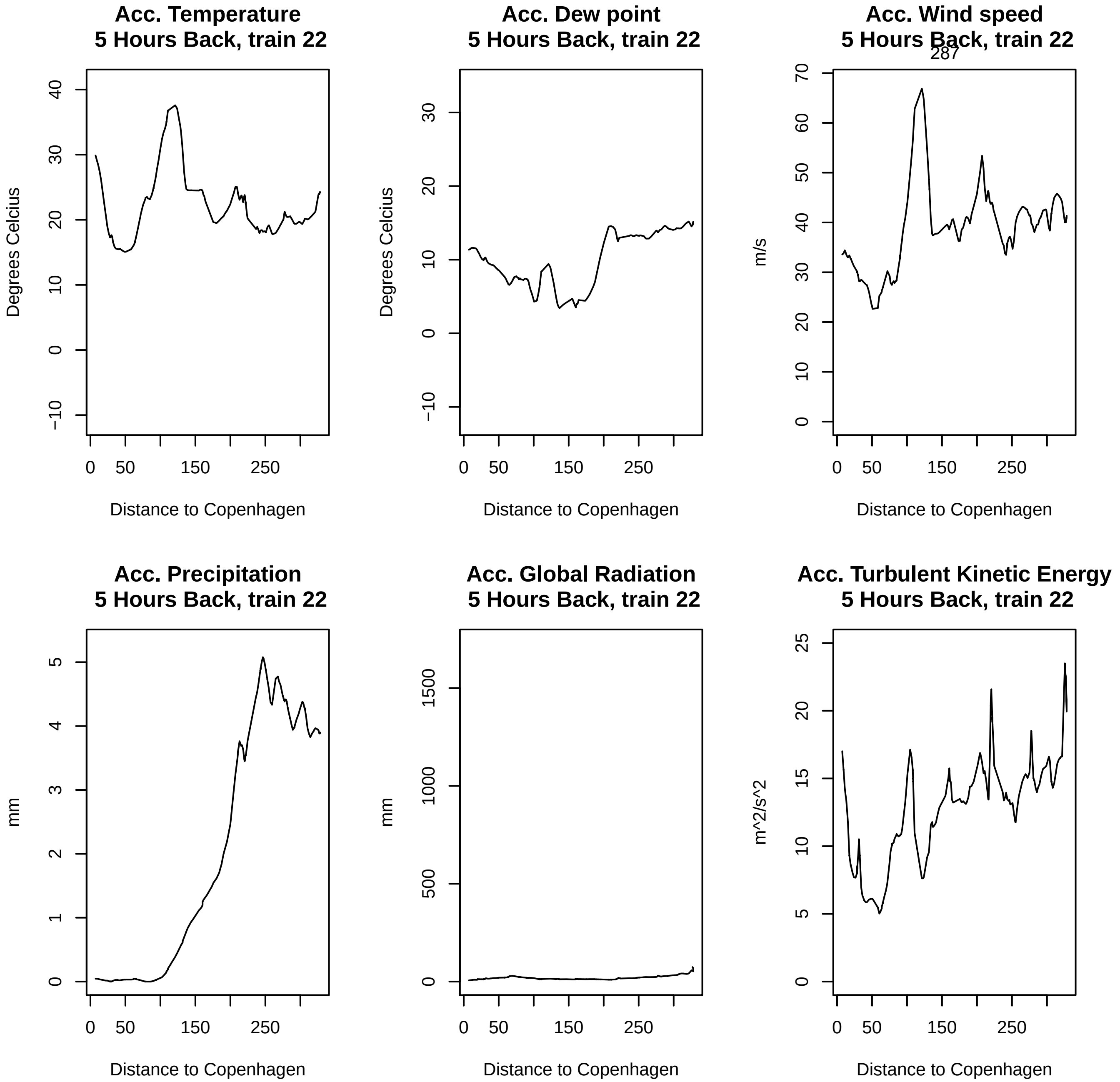

Acc. Temperature
24 Hours Back, train 21
Degrees Celcius
50
100
150
Acc. Dew point
24 Hours Back, train 21
Degrees Celcius
0
20
40
60
80
100
120
140
Acc. Wind speed
24 Hours Back, train 21
283
m/s
50
100
150
200
250
Acc. Precipitation
24 Hours Back, train 21
mm
0
2
4
6
8
10
12
Acc. Global Radiation
24 Hours Back, train 21
mm
0
500
1000
1500
Acc. Turbulent Kinetic Energy
24 Hours Back, train 21
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen


Temperature, train 22
Degrees Celcius
Distance to Copenhagen
Dew point, train 22
Degrees Celcius
Distance to Copenhagen
Wind speed, train 22
284
m/s
Distance to Copenhagen
Precipitation, train 22
mm
Distance to Copenhagen
Global Radiation, train 22
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 22
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 22
Degrees Celcius
−5
0
5
10
15
20
25
0
50
150
250
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 22
Degrees Celcius
−5
0
5
10
15
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 22
m/s
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 22
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 22
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 22
m^2/s^2
0
5
10
15
0
50
150
250
Distance to Copenhagen



Acc. Temperature
4 Hours Back, train 22
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 22
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 22
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 22
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 22
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 22
m^2/s^2
Distance to Copenhagen



Acc. Temperature
5 Hours Back, train 22
Degrees Celcius
−10
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Dew point
5 Hours Back, train 22
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
5 Hours Back, train 22
m/s
0
10
20
30
40
50
60
70
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
5 Hours Back, train 22
mm
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
5 Hours Back, train 22
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
5 Hours Back, train 22
m^2/s^2
0
5
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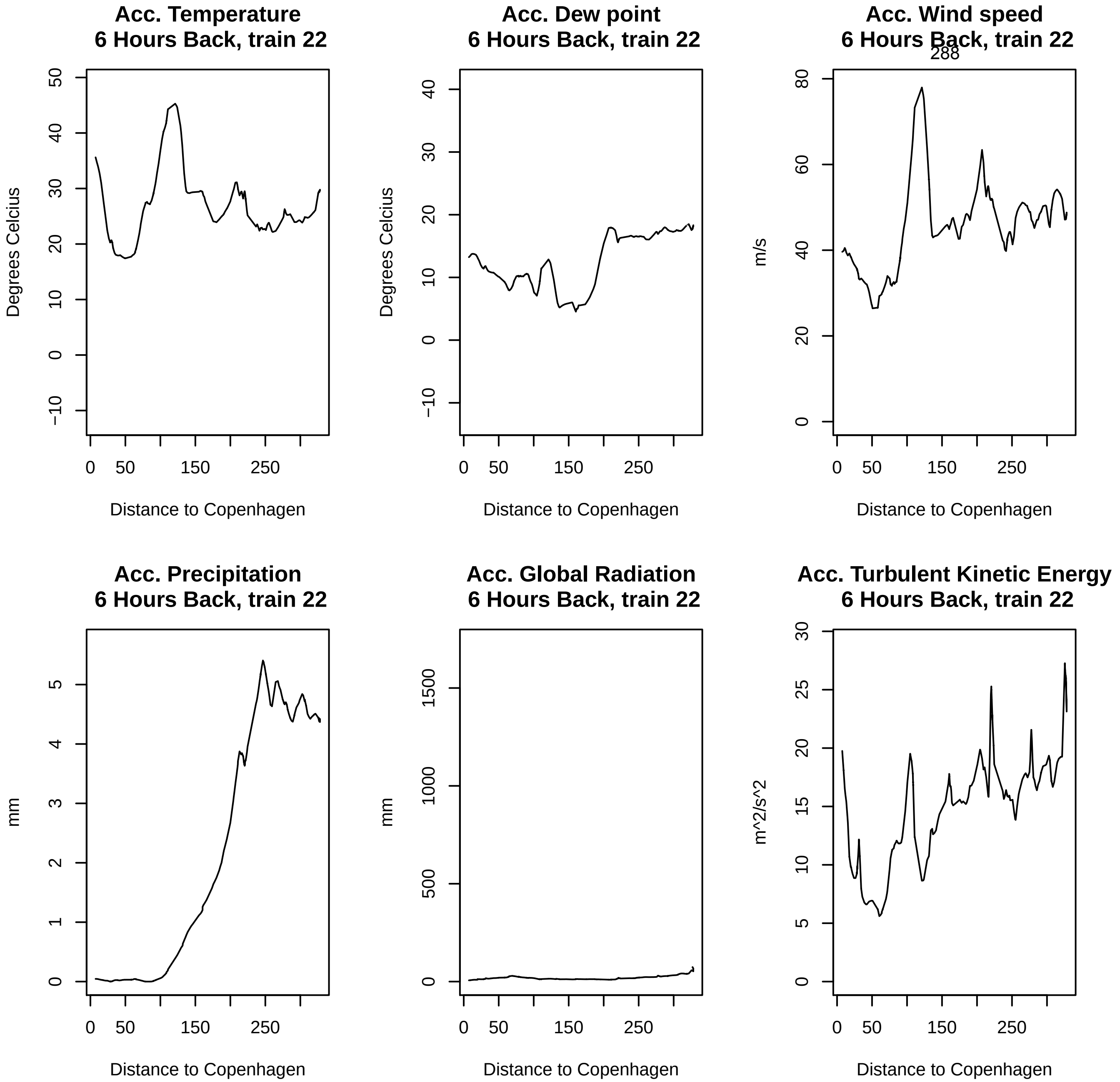
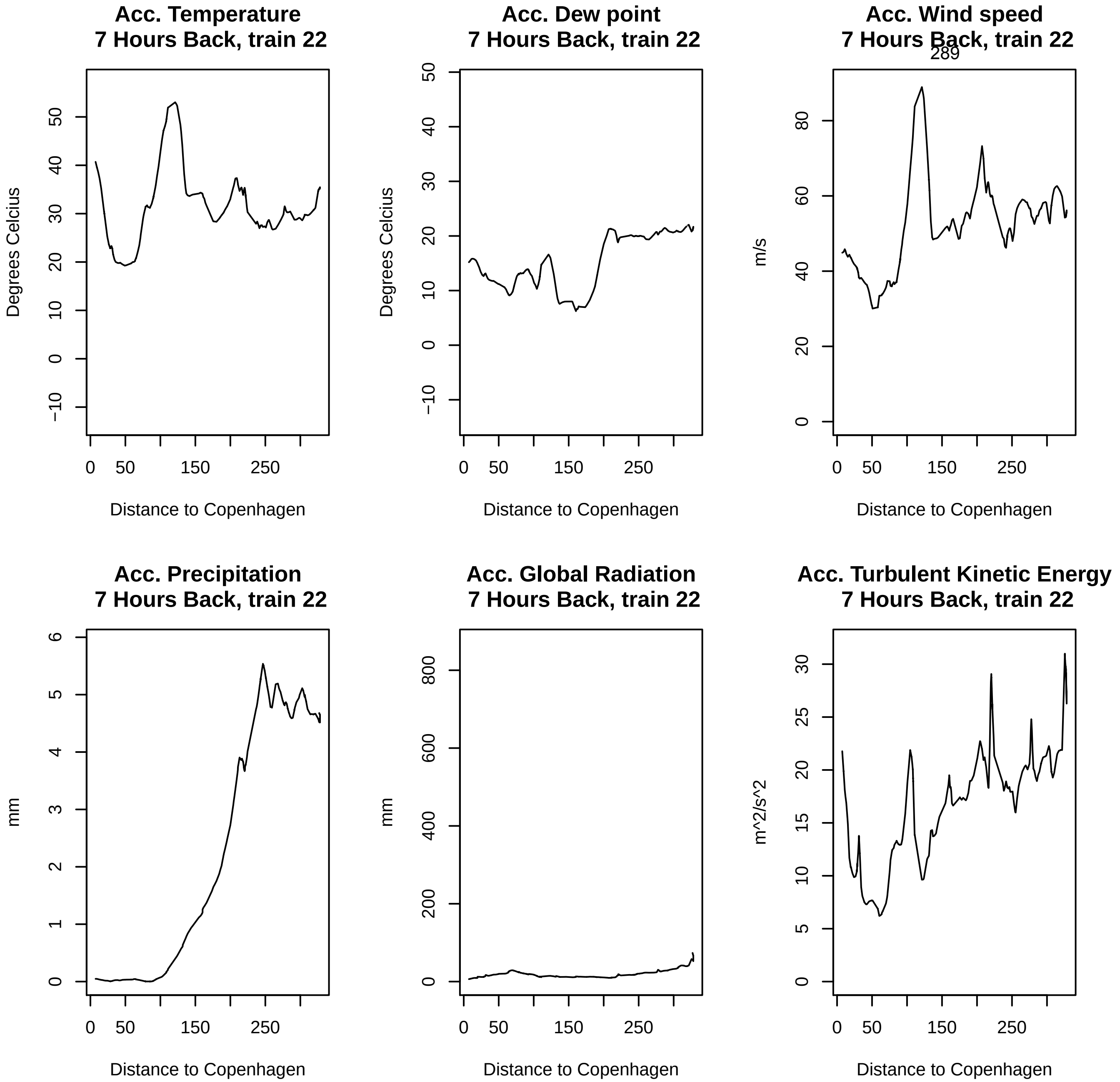
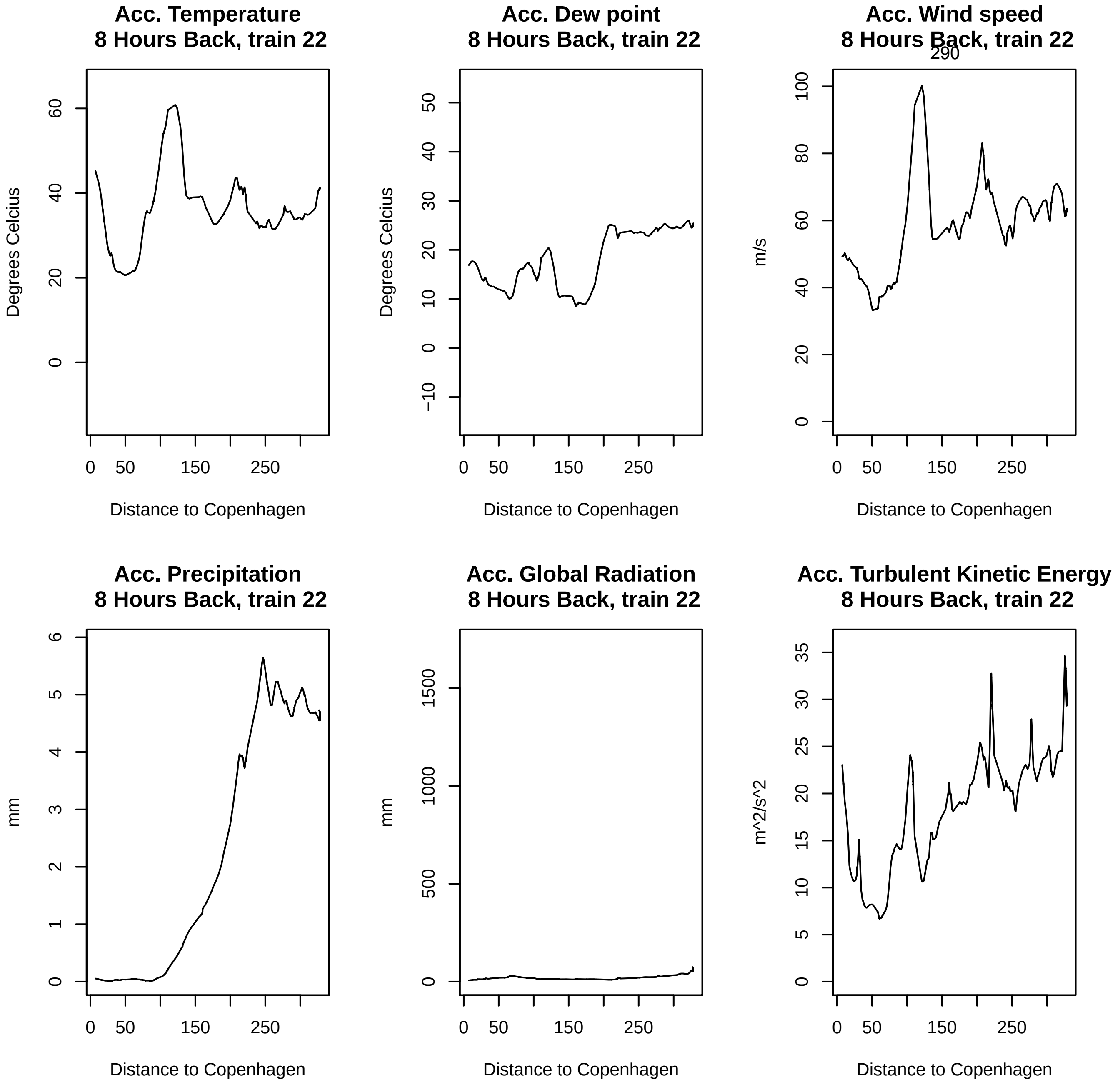
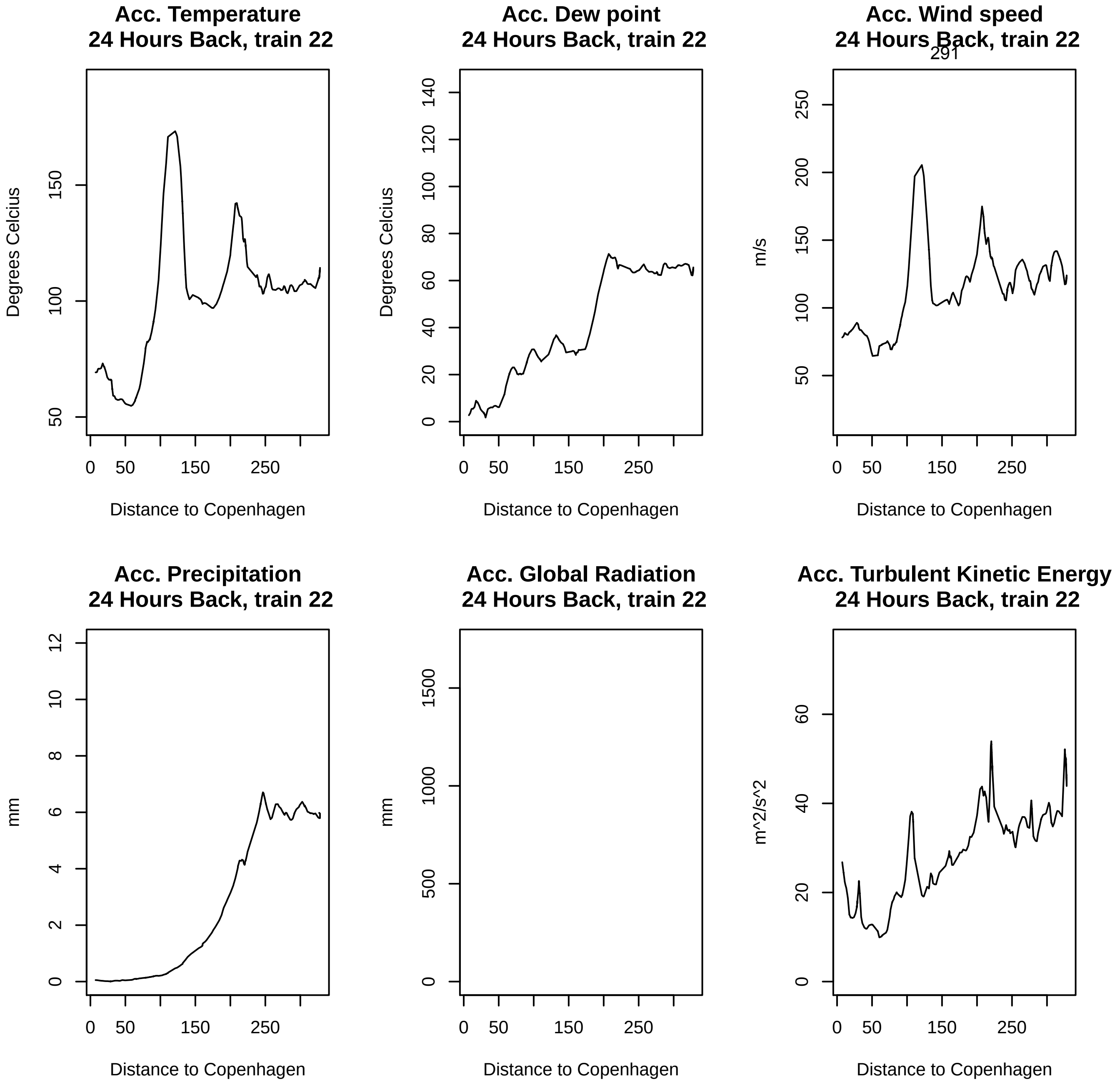
15
20
25
Distance to Copenhagen
0
50
150
250

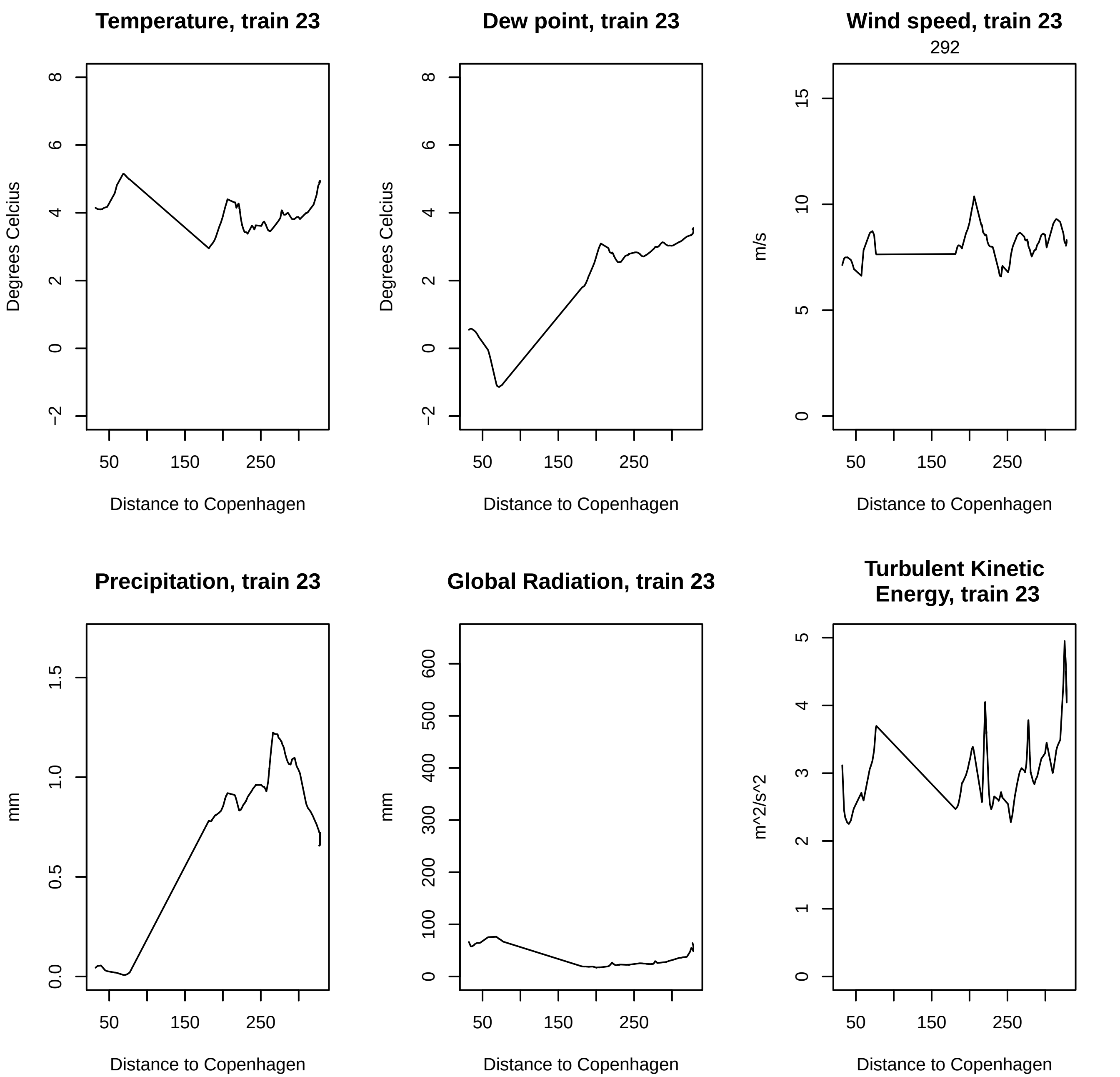

Acc. Temperature
6 Hours Back, train 22
Degrees Celcius
−10
0
10
20
30
40
50
Distance to Copenhagen
0
50
150
250
Acc. Dew point
6 Hours Back, train 22
Degrees Celcius
−10
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
6 Hours Back, train 22
m/s
0
20
40
60
80
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
6 Hours Back, train 22
mm
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
6 Hours Back, train 22
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
6 Hours Back, train 22
m^2/s^2
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250


Acc. Temperature
7 Hours Back, train 22
Degrees Celcius
−10 0 10 20 30 40 50
0 50 150 250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 22
Degrees Celcius
−10 0 10 20 30 40 50
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 22
m/s
0 20 40 60 80
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 22
mm
0 1 2 3 4 5 6
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 22
mm
0 200 400 600 800
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 22
m^2/s^2
0 5 10 15 20 25 30
0 50 150 250
Distance to Copenhagen

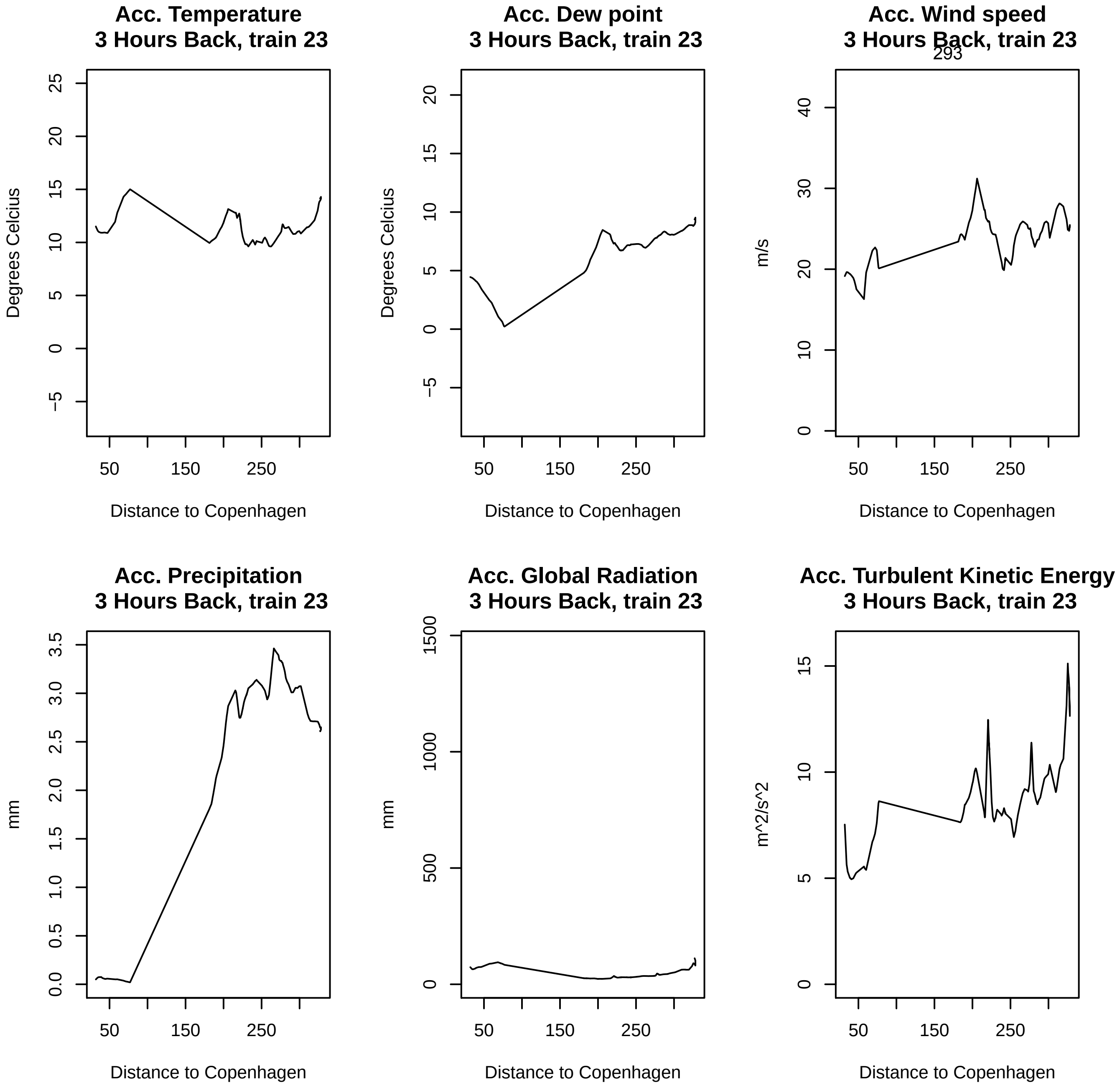


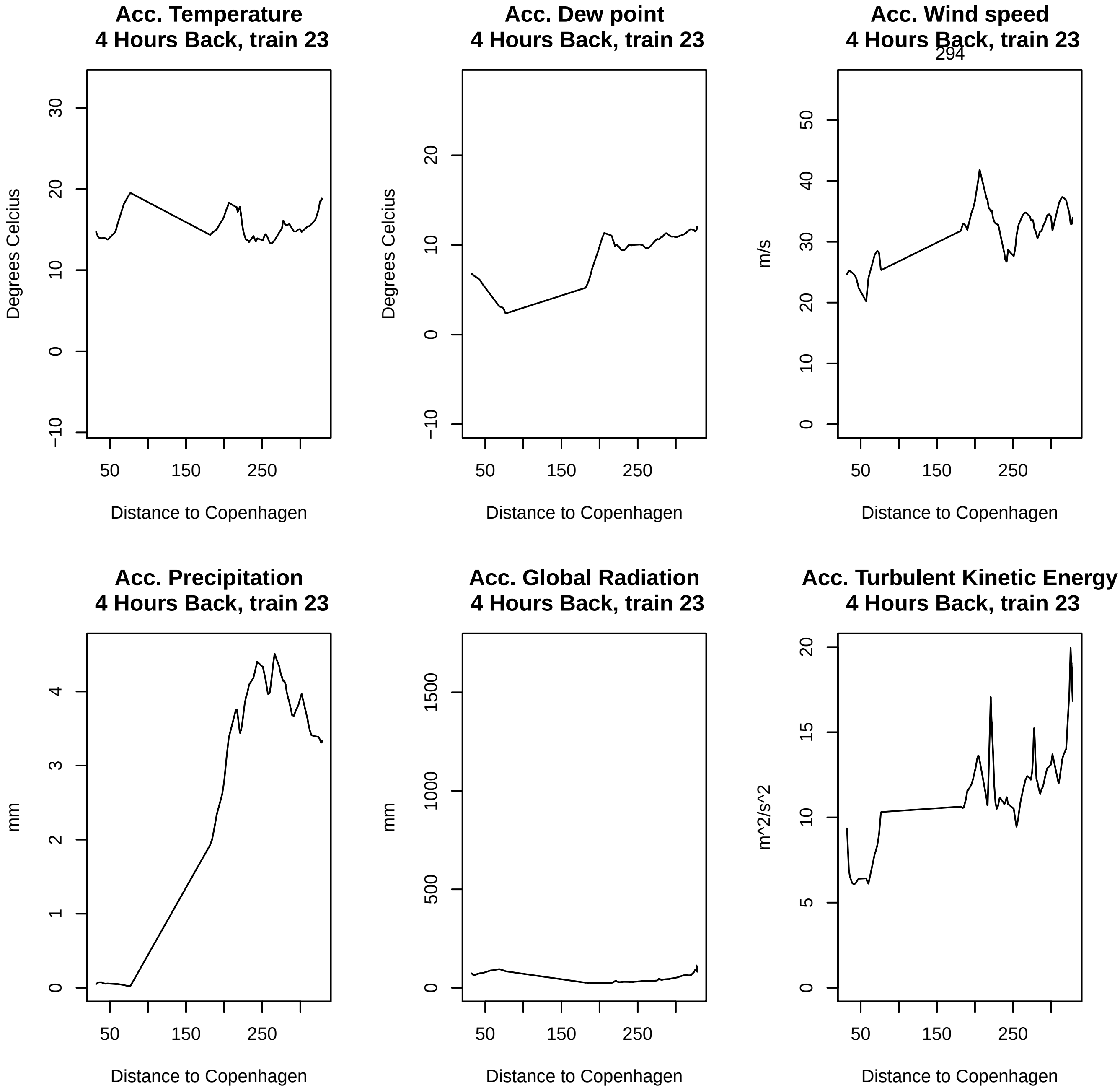
Acc. Temperature
8 Hours Back, train 22
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 22
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 22
290
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 22
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 22
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 22
m^2/s^2
Distance to Copenhagen

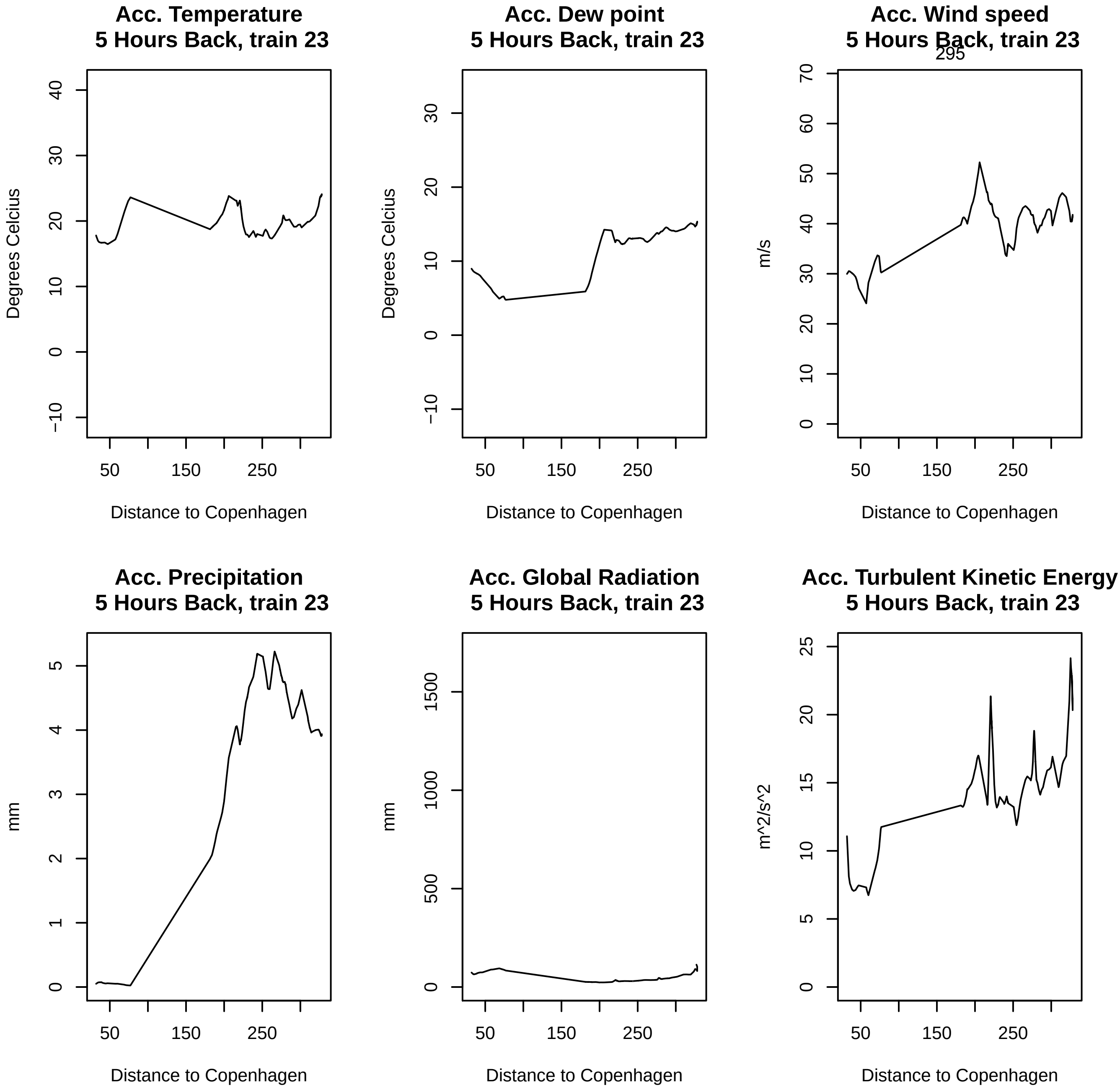

Acc. Temperature
24 Hours Back, train 22
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 22
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 22
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 22
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 22
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 22
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

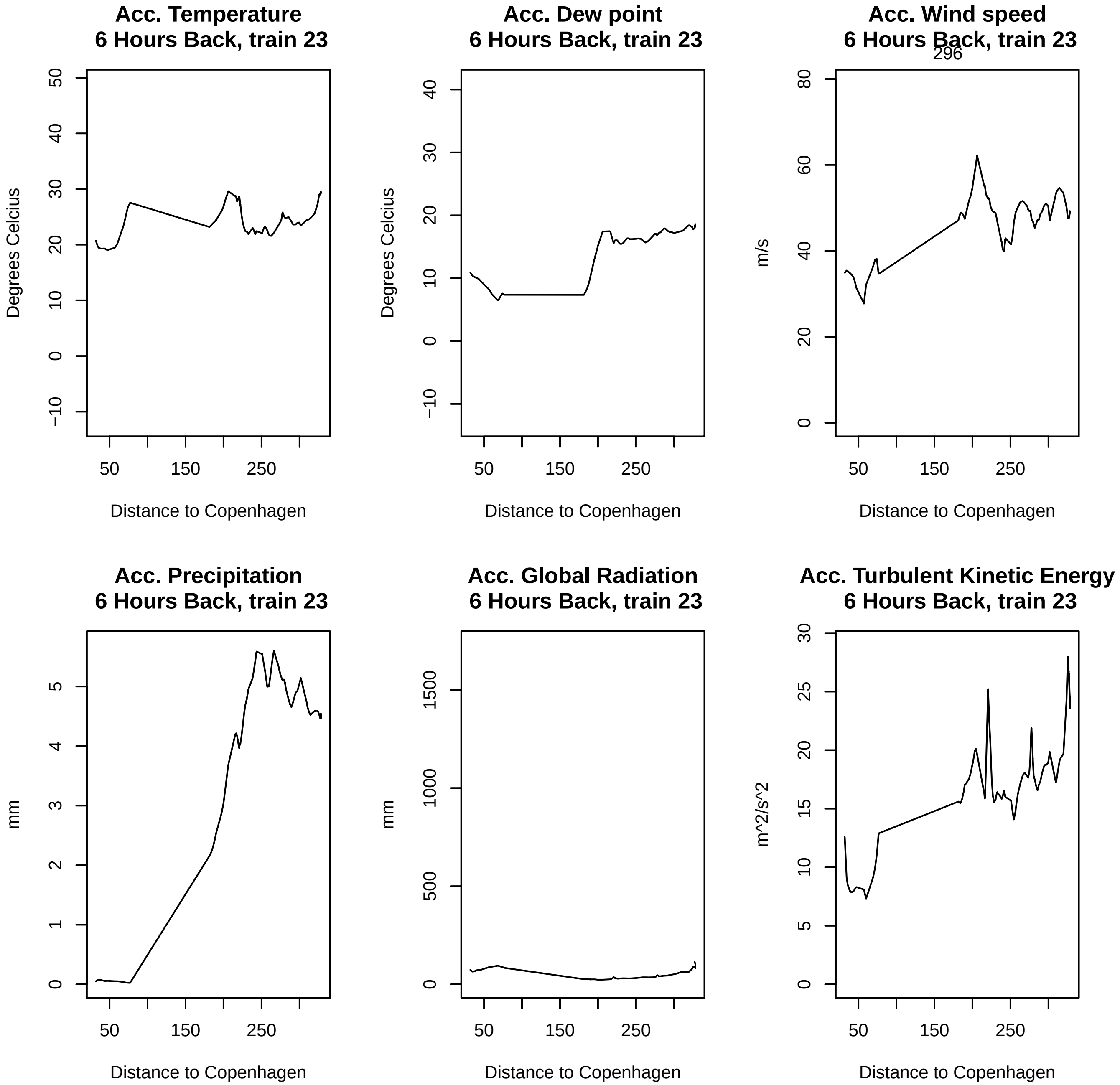


Temperature, train 23
Degrees Celcius
−2
0
2
4
6
8
50
150
250
Distance to Copenhagen
Dew point, train 23
Degrees Celcius
−2
0
2
4
6
8
50
150
250
Distance to Copenhagen
Wind speed, train 23
292
m/s
0
5
10
15
50
150
250
Distance to Copenhagen
Precipitation, train 23
mm
0.0
0.5
1.0
1.5
50
150
250
Distance to Copenhagen
Global Radiation, train 23
mm
0
100
200
300
400
500
600
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 23
m^2/s^2
0
1
2
3
4
5
50
150
250
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 23
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 23
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 23
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 23
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 23
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 23
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 23
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 23
m^2/s^2
Distance to Copenhagen
50
150
250


Acc. Temperature
6 Hours Back, train 23
Degrees Celcius
−10
0
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20
30
40
50
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 23
Degrees Celcius
−10
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10
20
30
40
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 23
m/s
0
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50
150
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Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 23
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4
5
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150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 23
mm
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150
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Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 23
m^2/s^2
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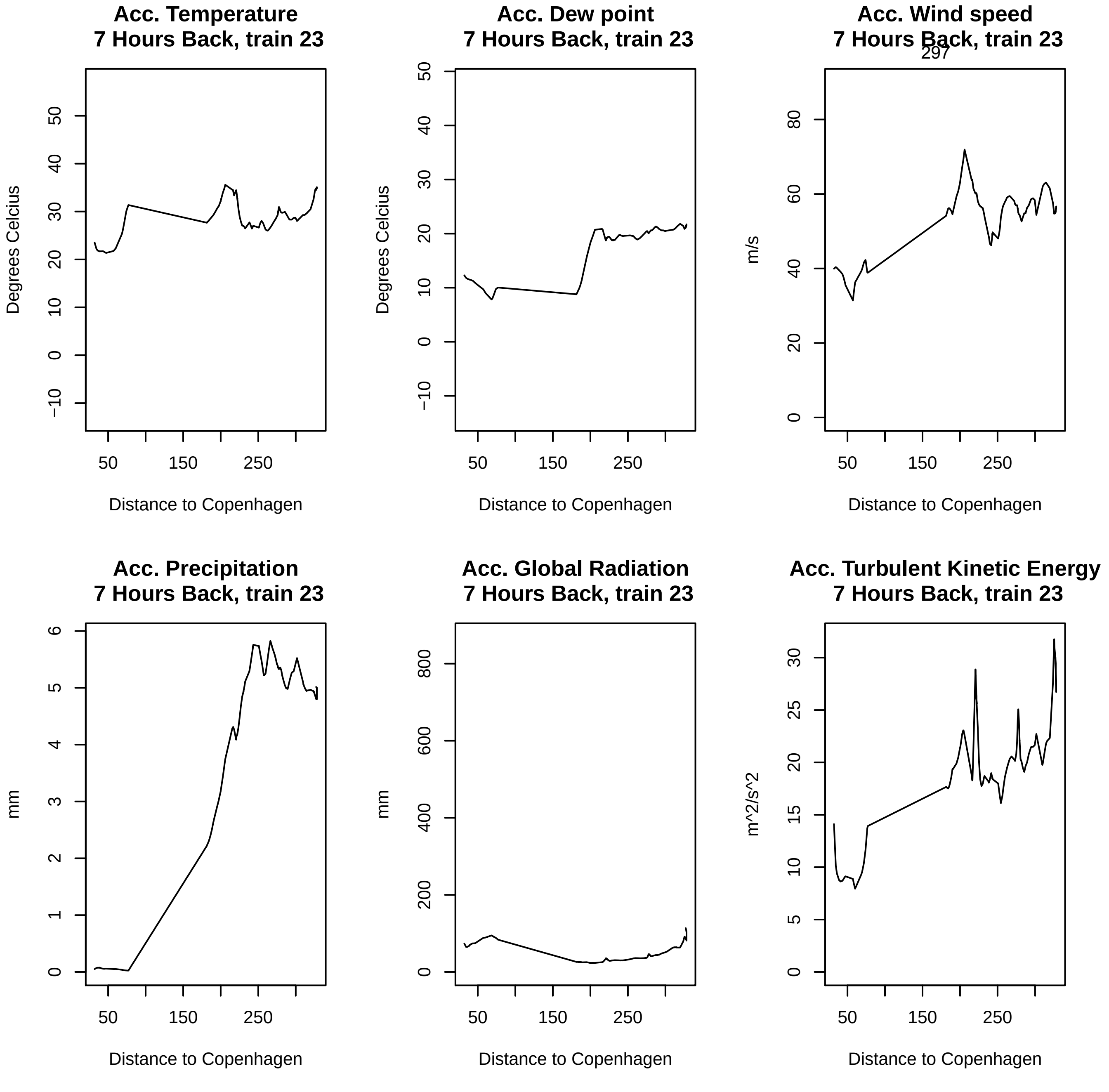
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 23
Degrees Celcius
−10
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50
150
250
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 23
Degrees Celcius
−10
0
10
20
30
40
50
50
150
250
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 23
m/s
0
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40
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80
50
150
250
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 23
mm
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150
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Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 23
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Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 23
m^2/s^2
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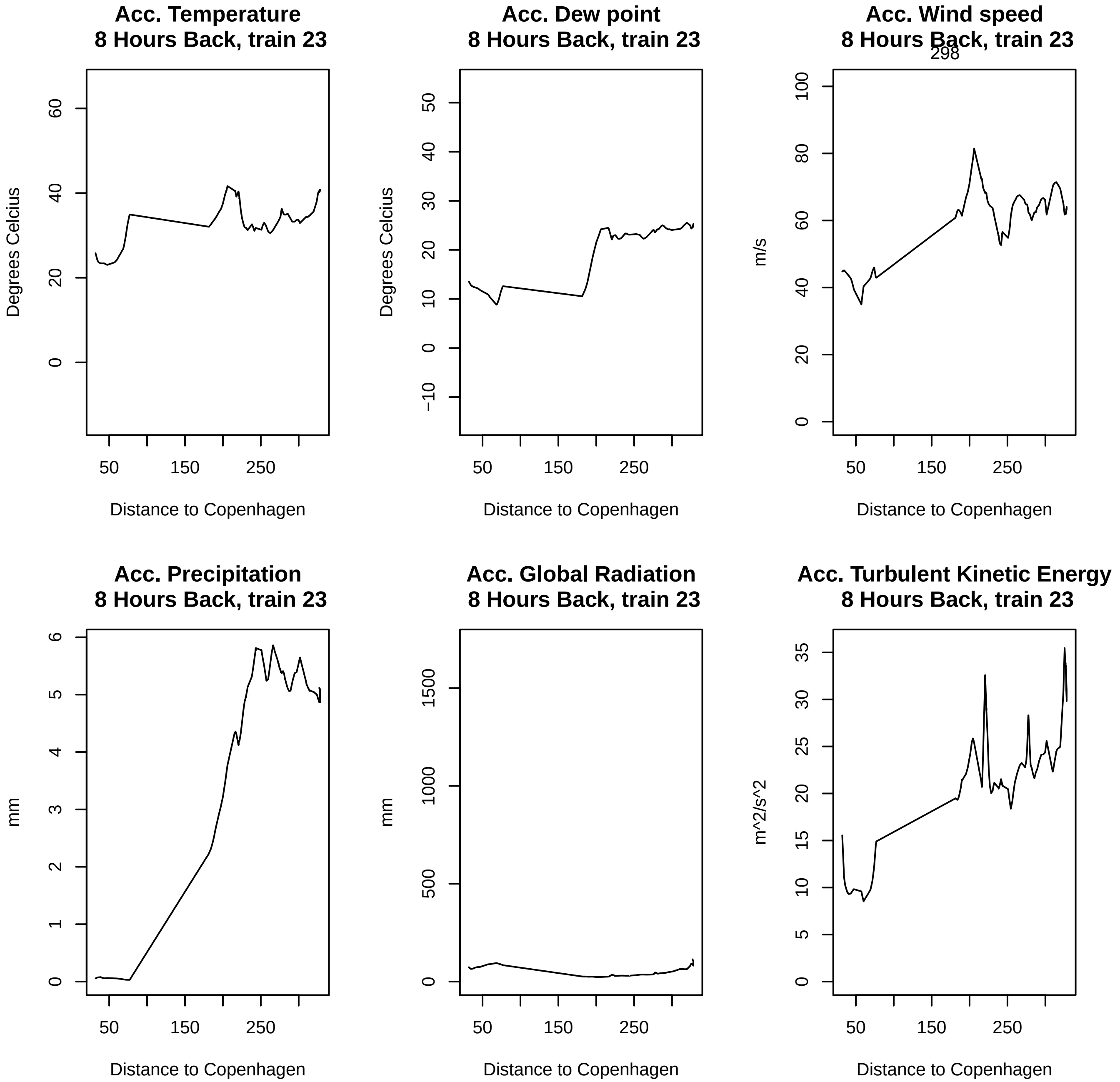
Distance to Copenhagen



Acc. Temperature
8 Hours Back, train 23
Degrees Celcius
0
20
40
60
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 23
Degrees Celcius
−10
0
10
20
30
40
50
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 23
m/s
0
20
40
60
80
100
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 23
mm
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1
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4
5
6
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 23
mm
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1000
1500
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 23
m^2/s^2
0
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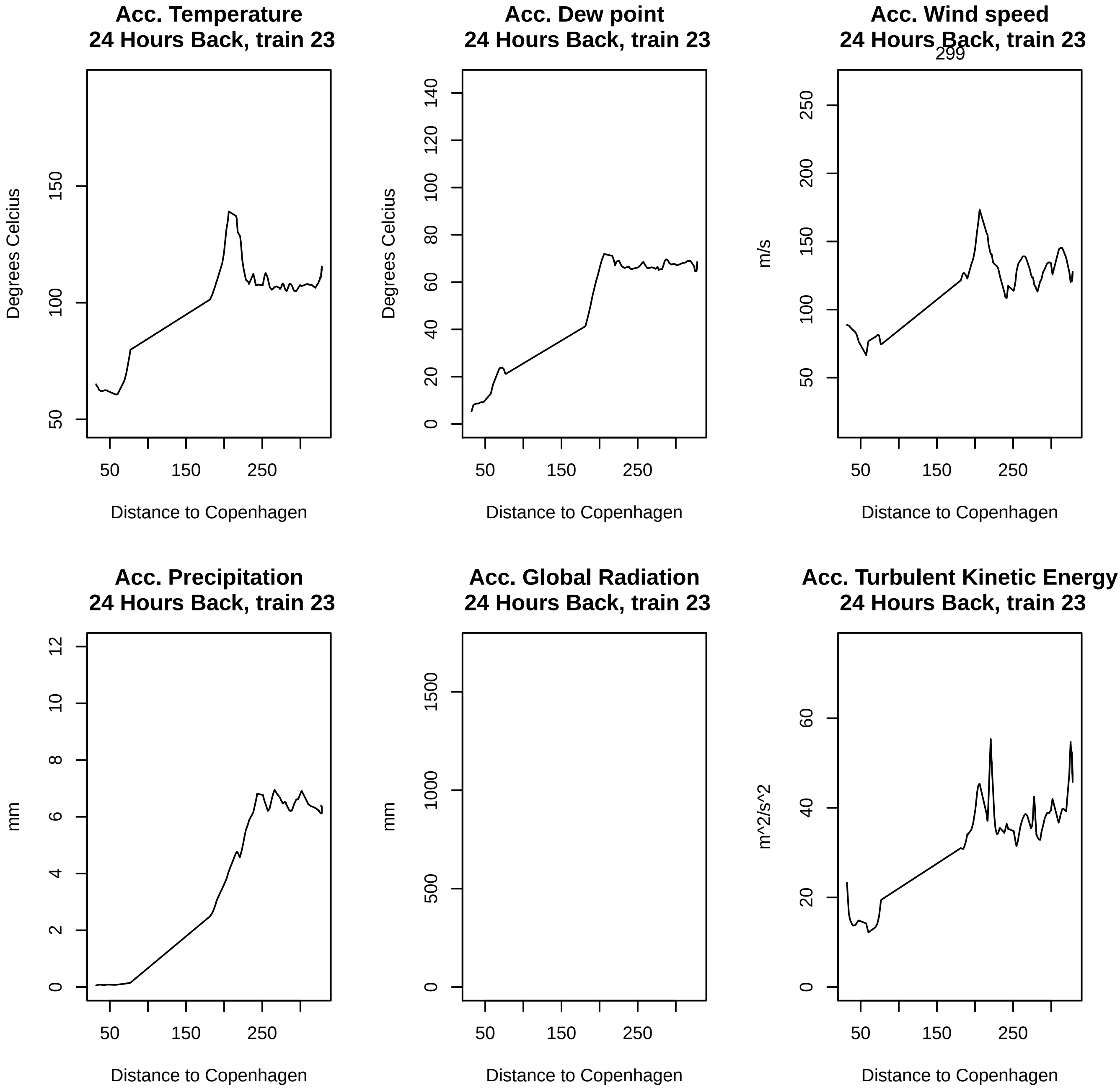
10
15
20
25
30
35
50
150
250
Distance to Copenhagen



Acc. Temperature
24 Hours Back, train 23
Degrees Celcius
50
100
150
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 23
Degrees Celcius
0
20
40
60
80
100
120
140
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 23
299
m/s
50
100
150
200
250
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 23
mm
0
2
4
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8
10
12
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 23
mm
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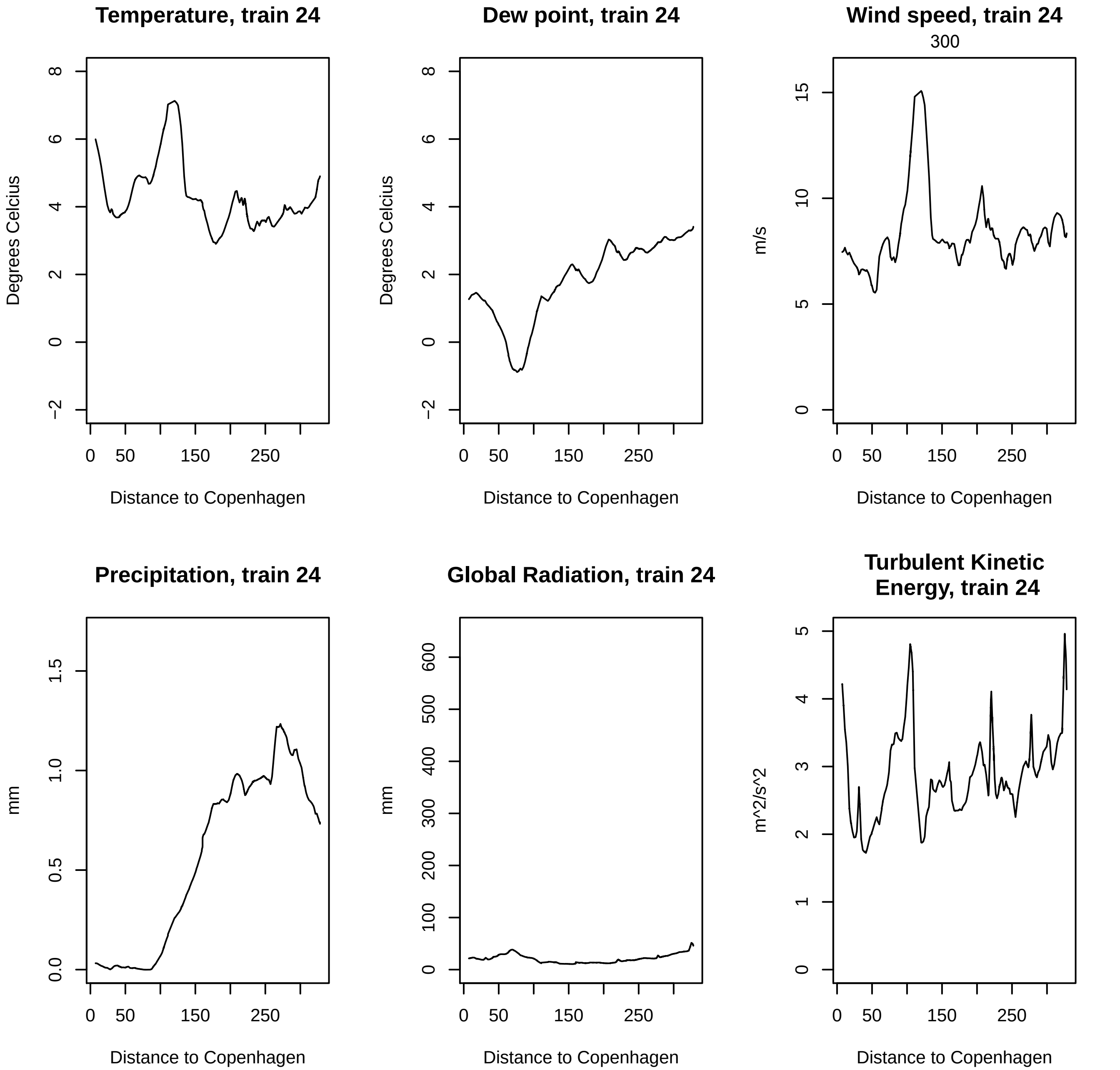
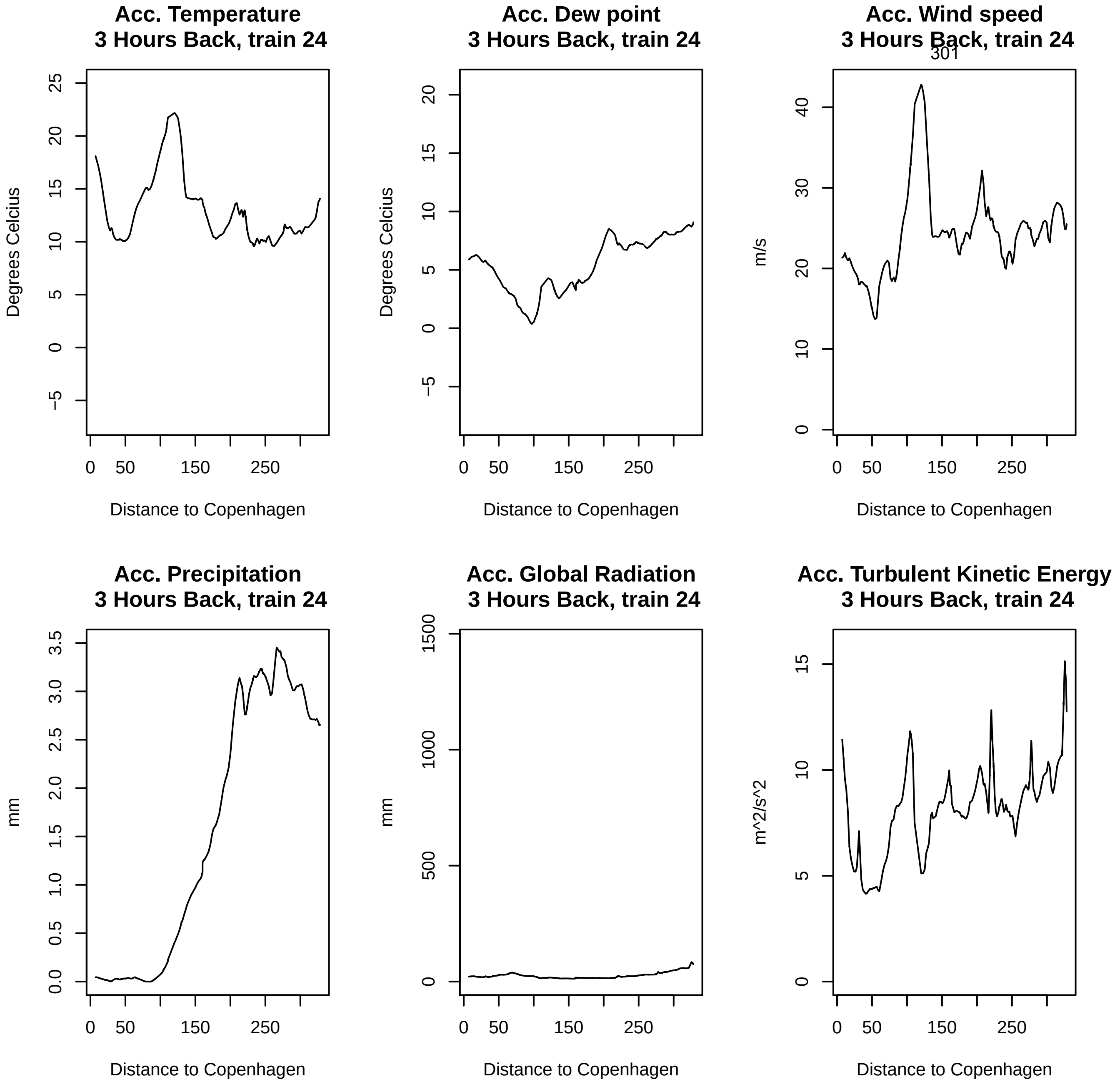
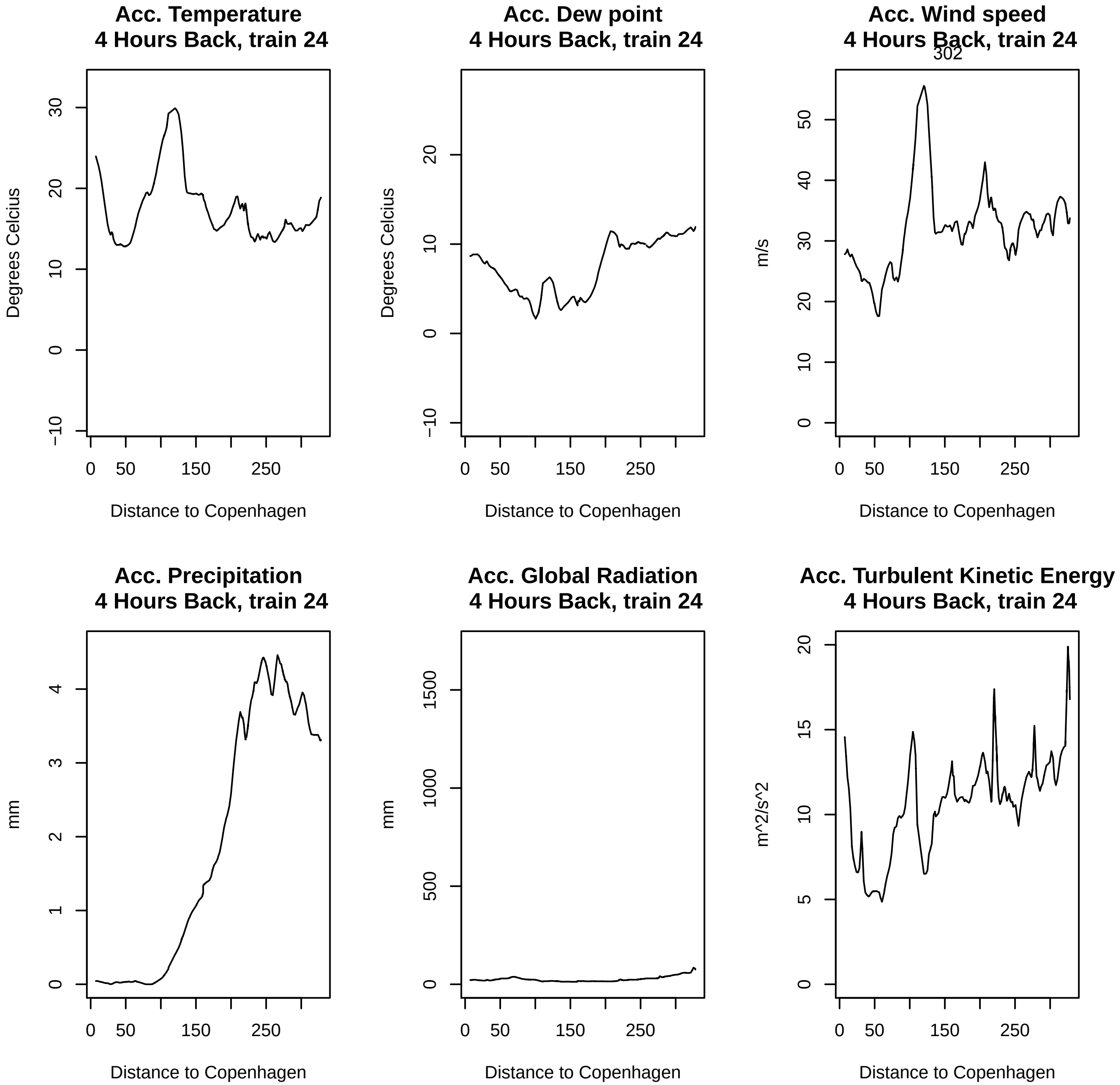
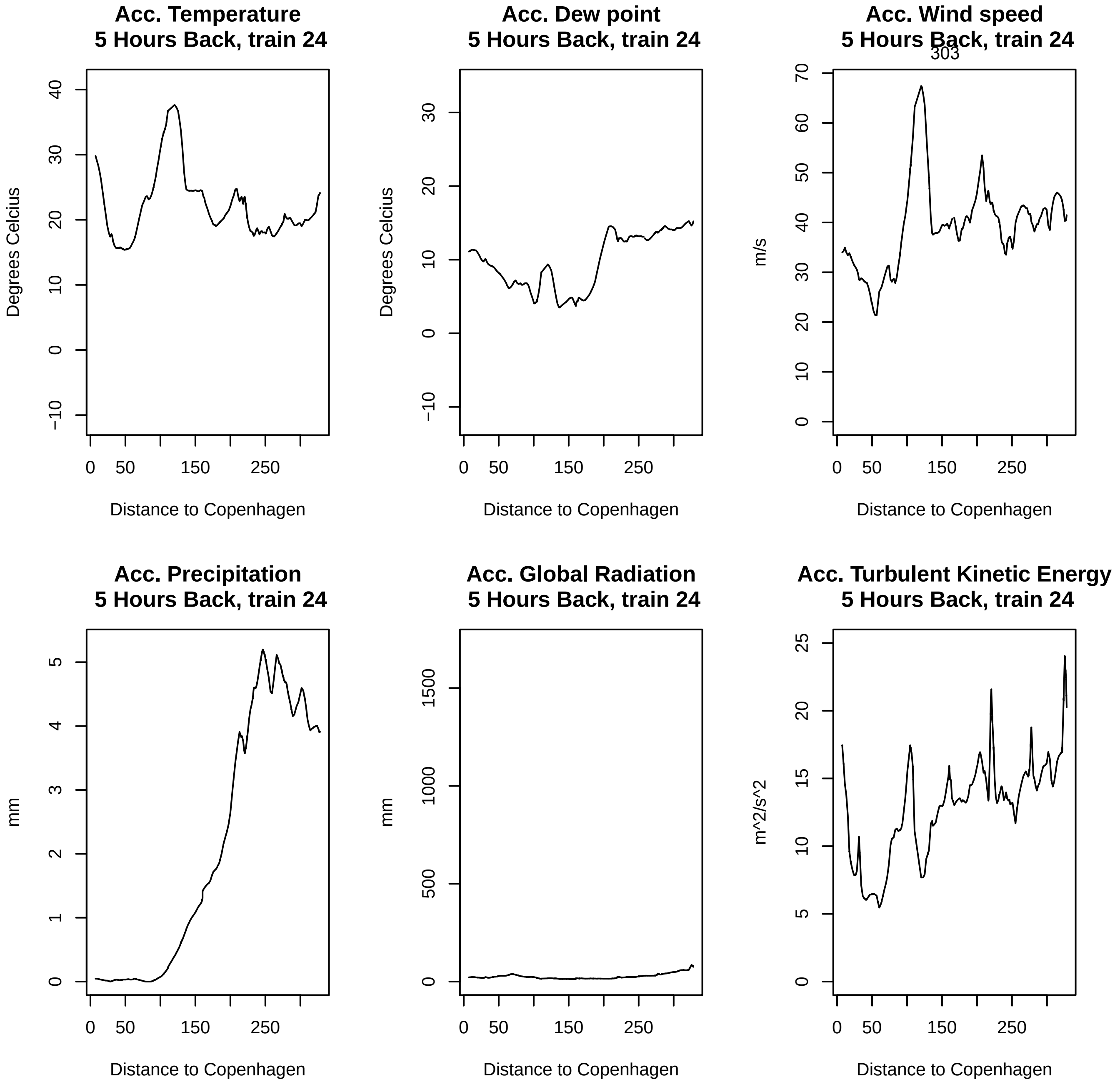
500
1000
1500
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 23
m^2/s^2
0
20
40
60
50
150
250
Distance to Copenhagen

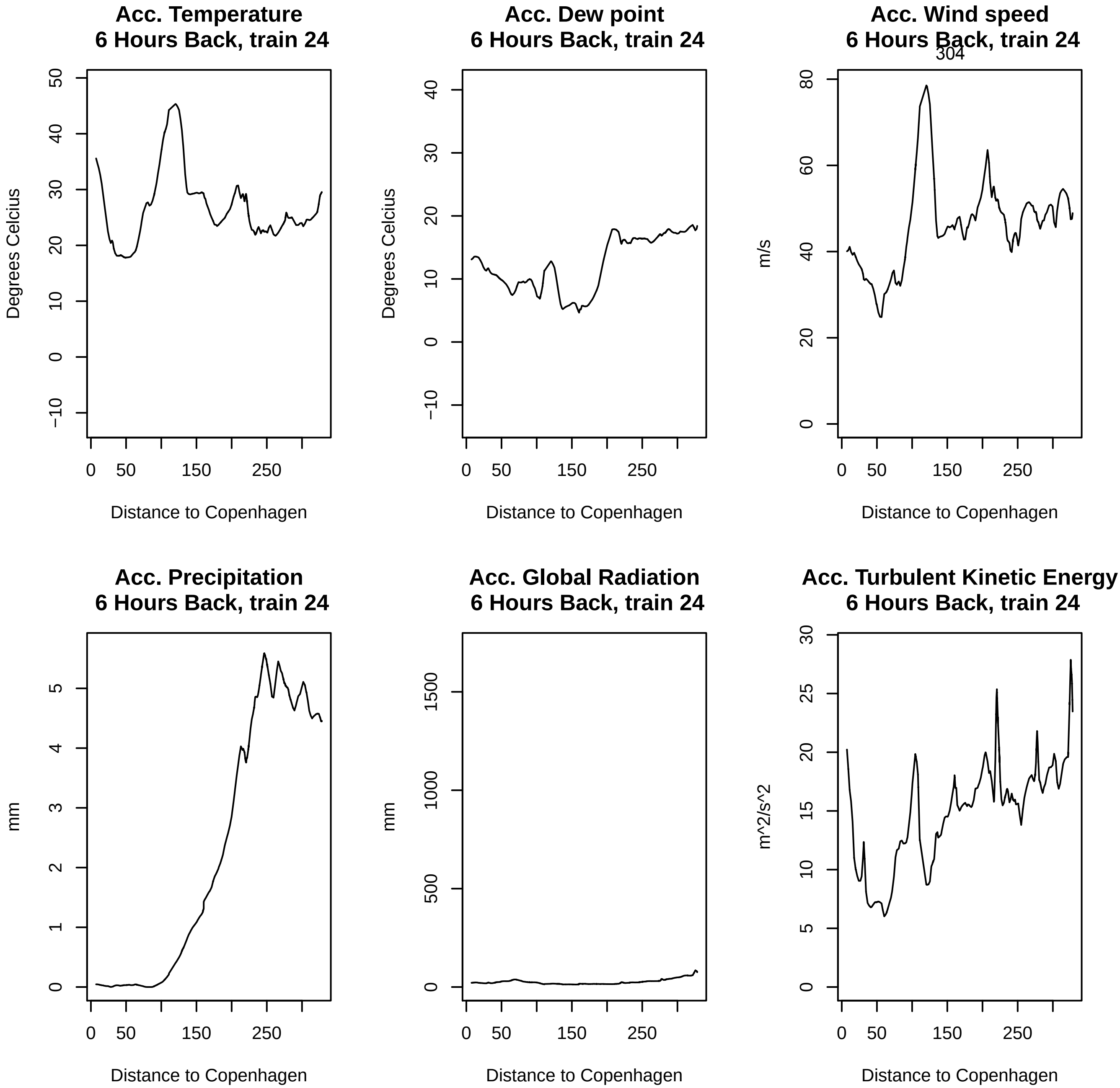


Temperature, train 24
Degrees Celcius
Distance to Copenhagen
Dew point, train 24
Degrees Celcius
Distance to Copenhagen
Wind speed, train 24
m/s
Distance to Copenhagen
Precipitation, train 24
mm
Distance to Copenhagen
Global Radiation, train 24
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 24
m^2/s^2
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 24
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 24
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 24
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 24
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 24
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 24
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 24
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 24
Degrees Celcius
−10
0
10
20
30
40
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 24
304
m/s
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20
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0
50
150
250
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 24
mm
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3
4
5
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 24
mm
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1000
1500
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50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 24
m^2/s^2
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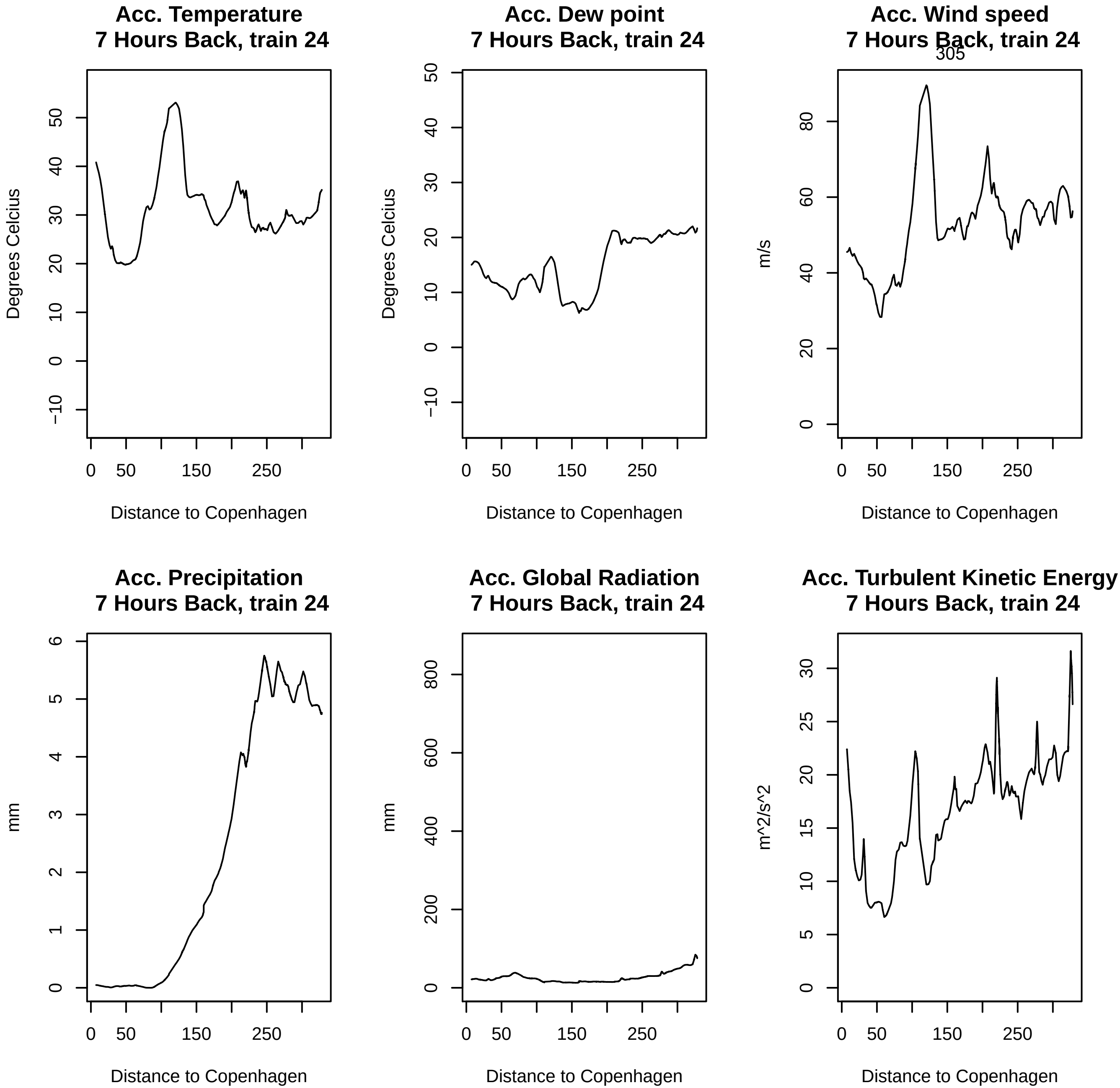
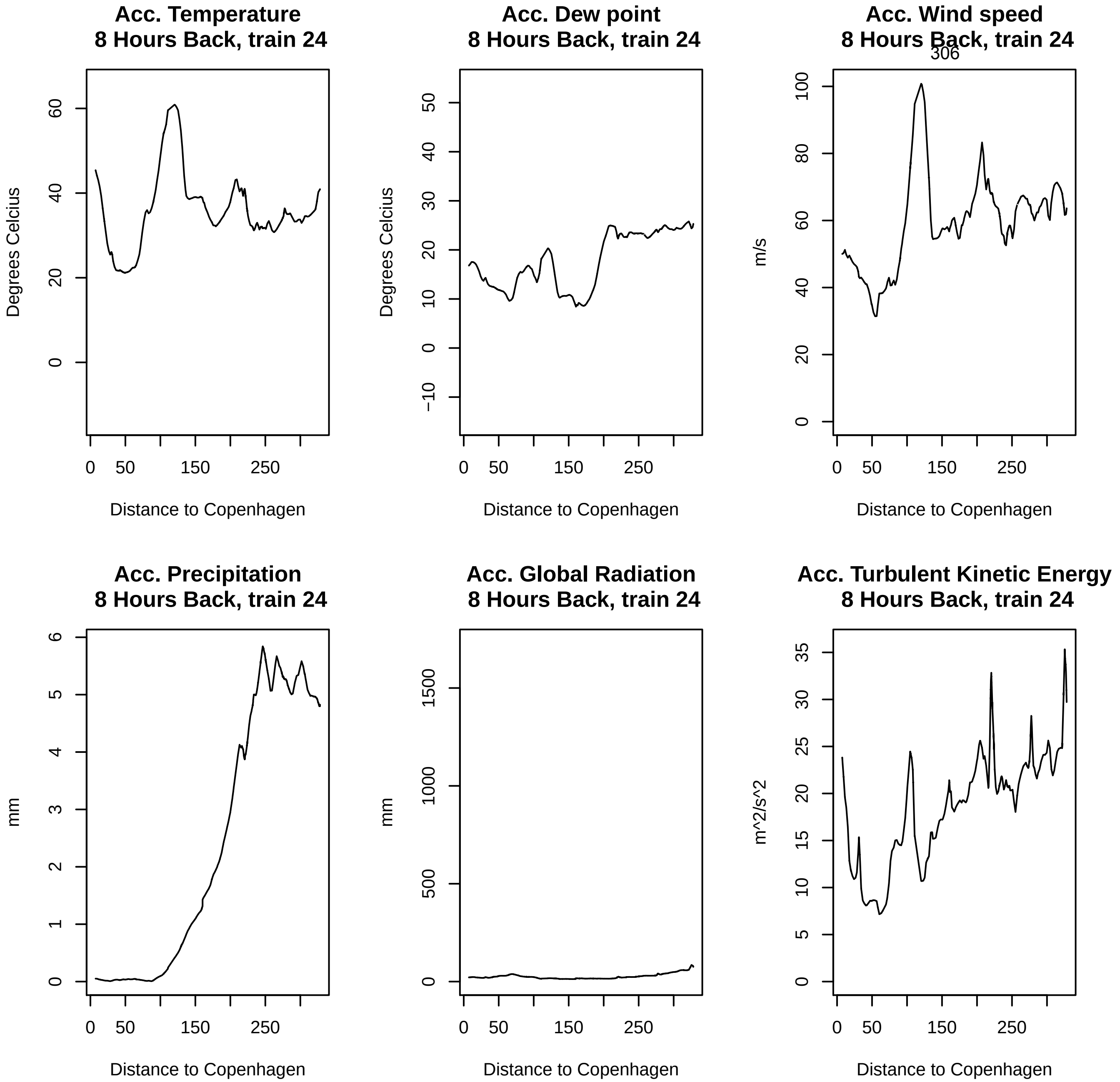
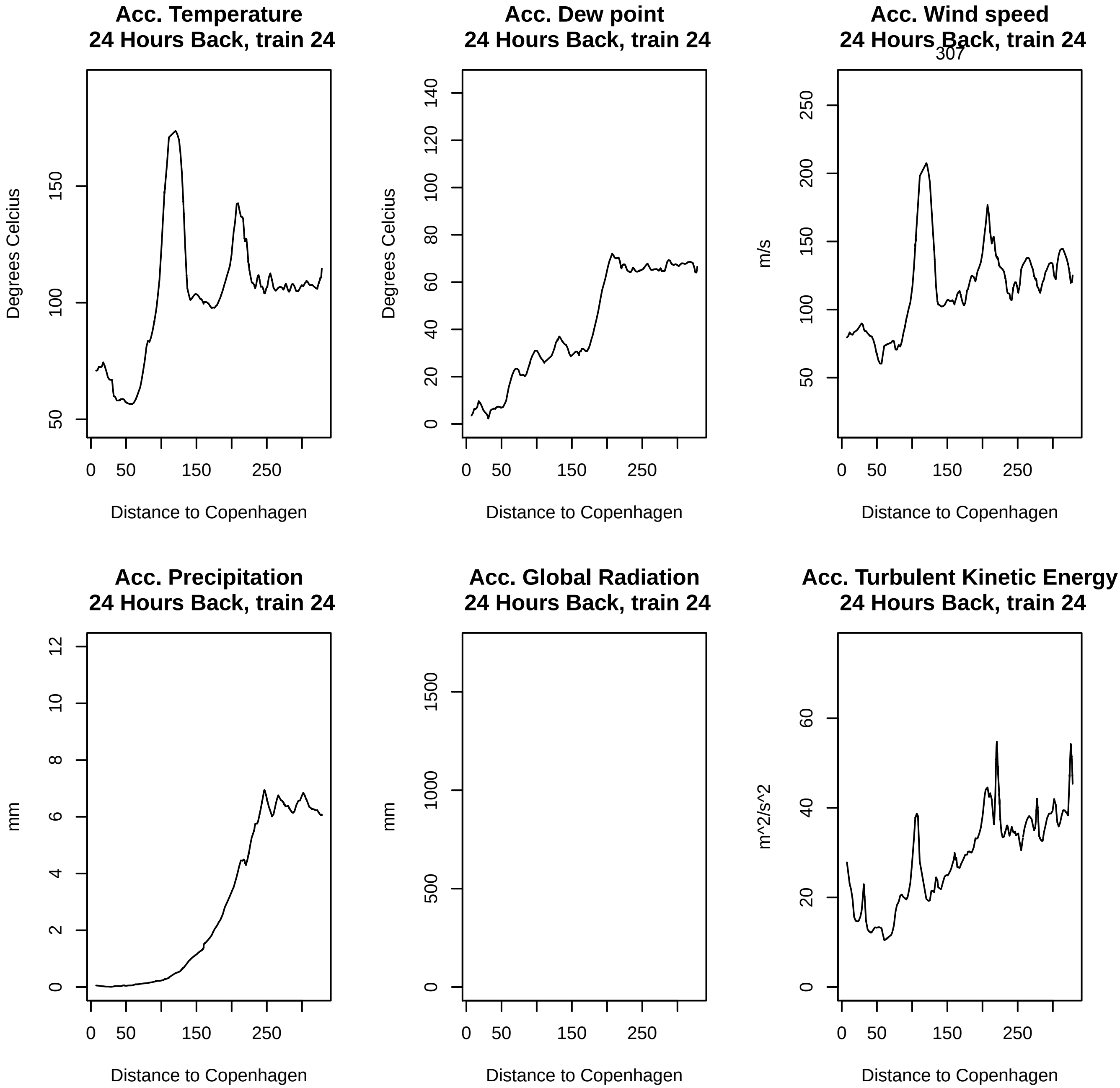
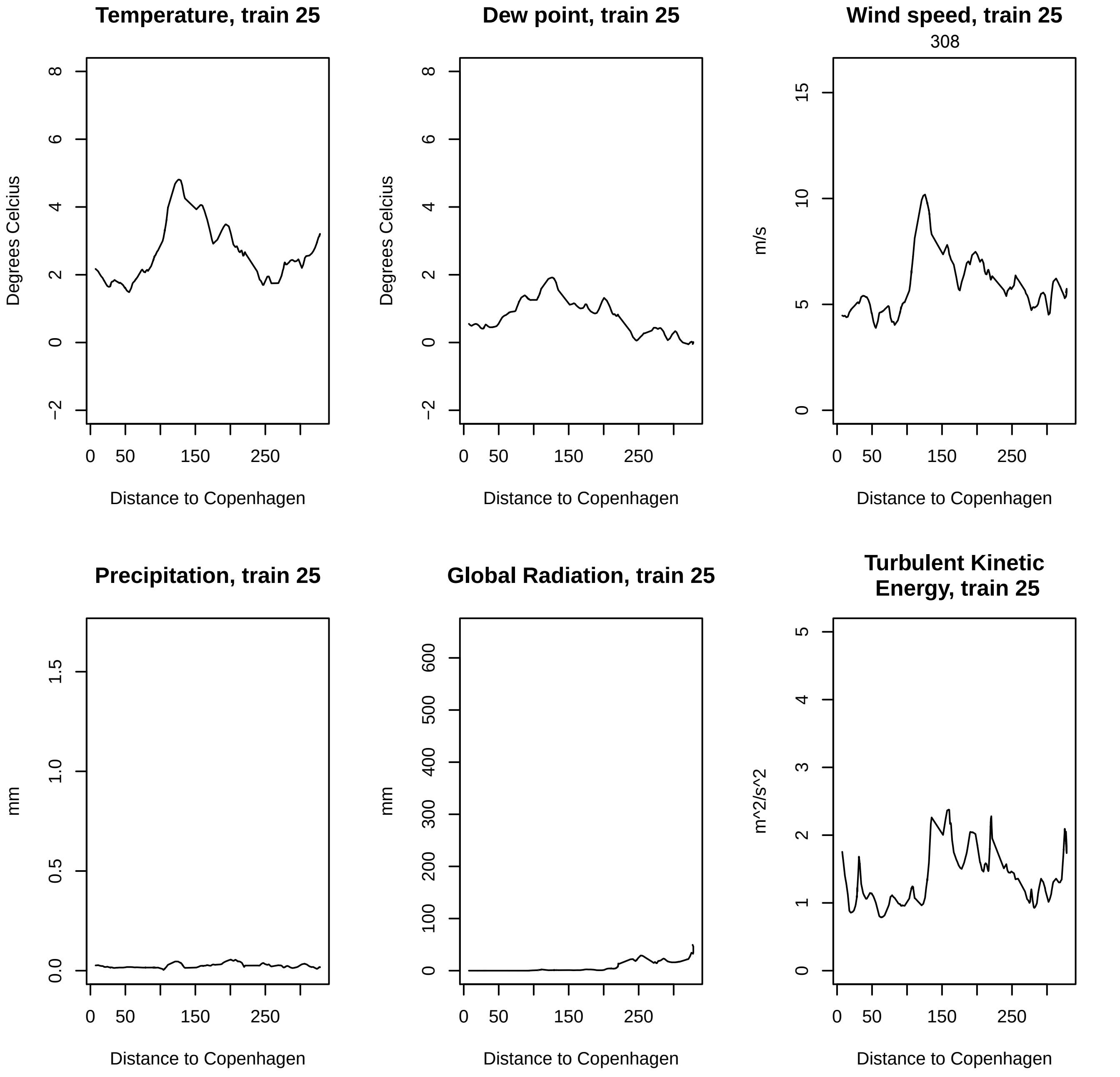
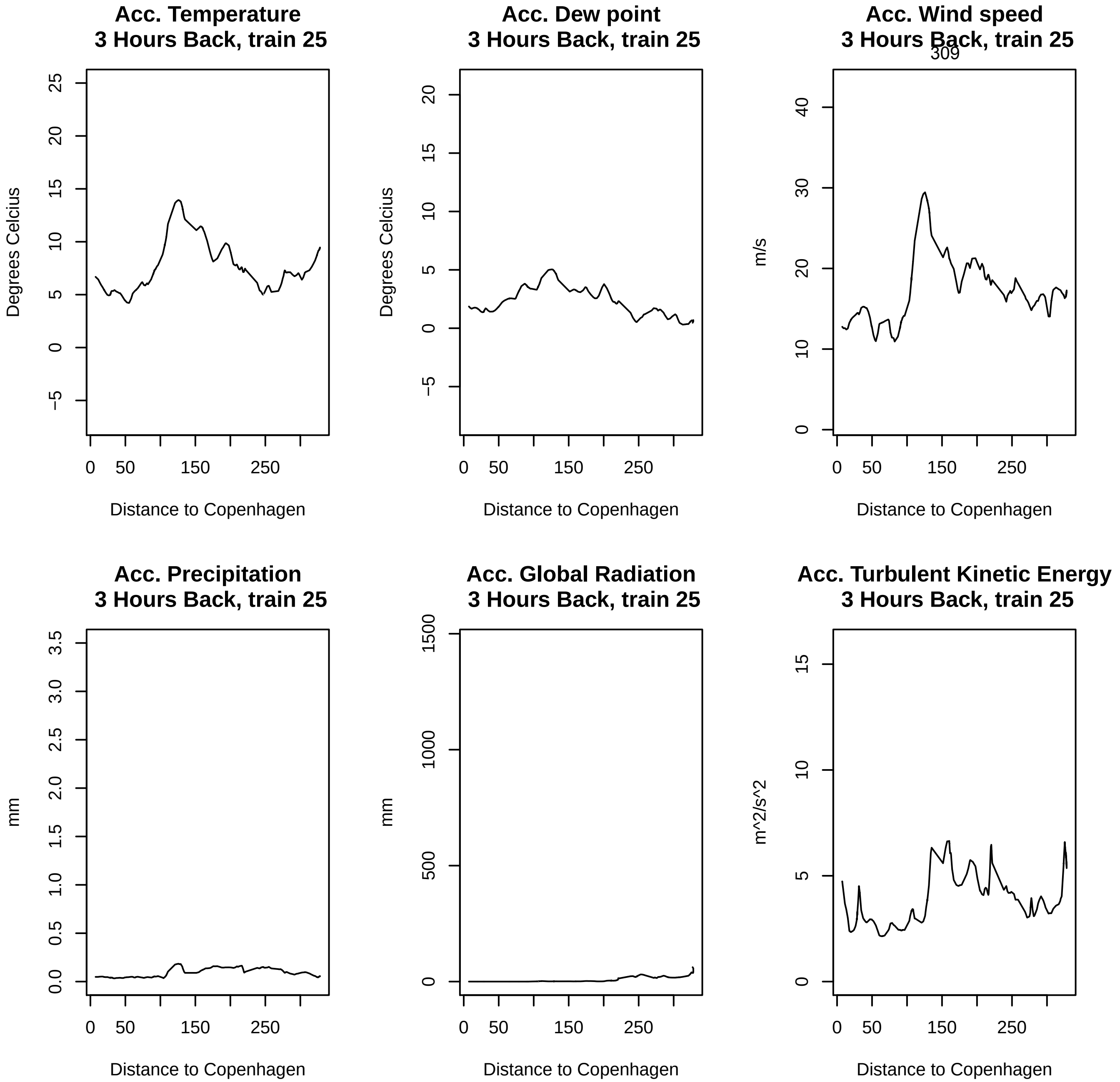
25
30
0
50
150
250
Distance to Copenhagen


Acc. Temperature
7 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 24
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 24
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 24
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 24
m^2/s^2
Distance to Copenhagen

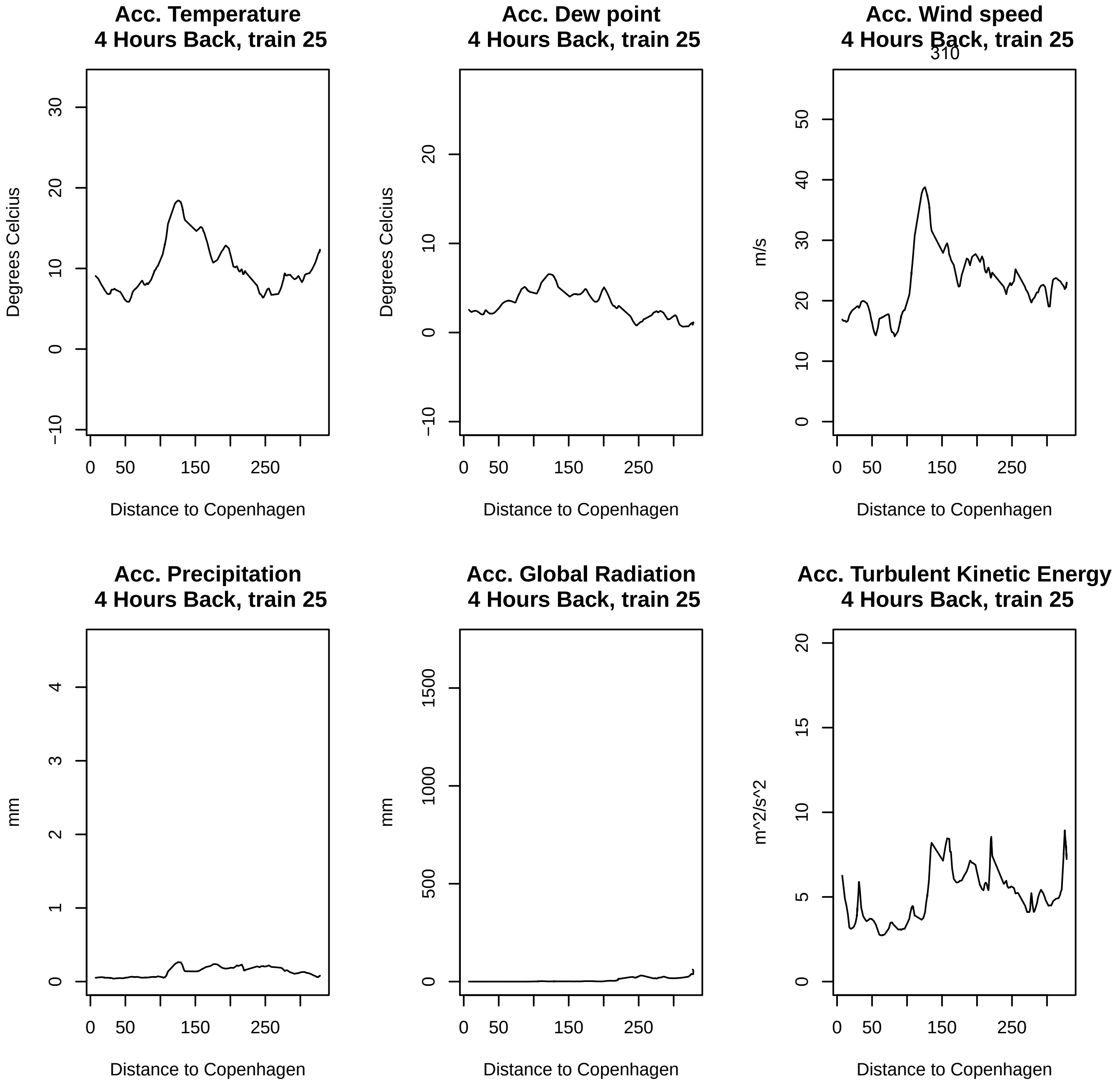

Acc. Temperature
8 Hours Back, train 24
Degrees Celcius
0
20
40
60
0 50 150 250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 24
Degrees Celcius
−10
0
10
20
30
40
50
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 24
m/s
0
20
40
60
80
100
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 24
mm
0
1
2
3
4
5
6
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 24
mm
0
500
1000
1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 24
m^2/s^2
0
5
10
15
20
25
30
35
0 50 150 250
Distance to Copenhagen

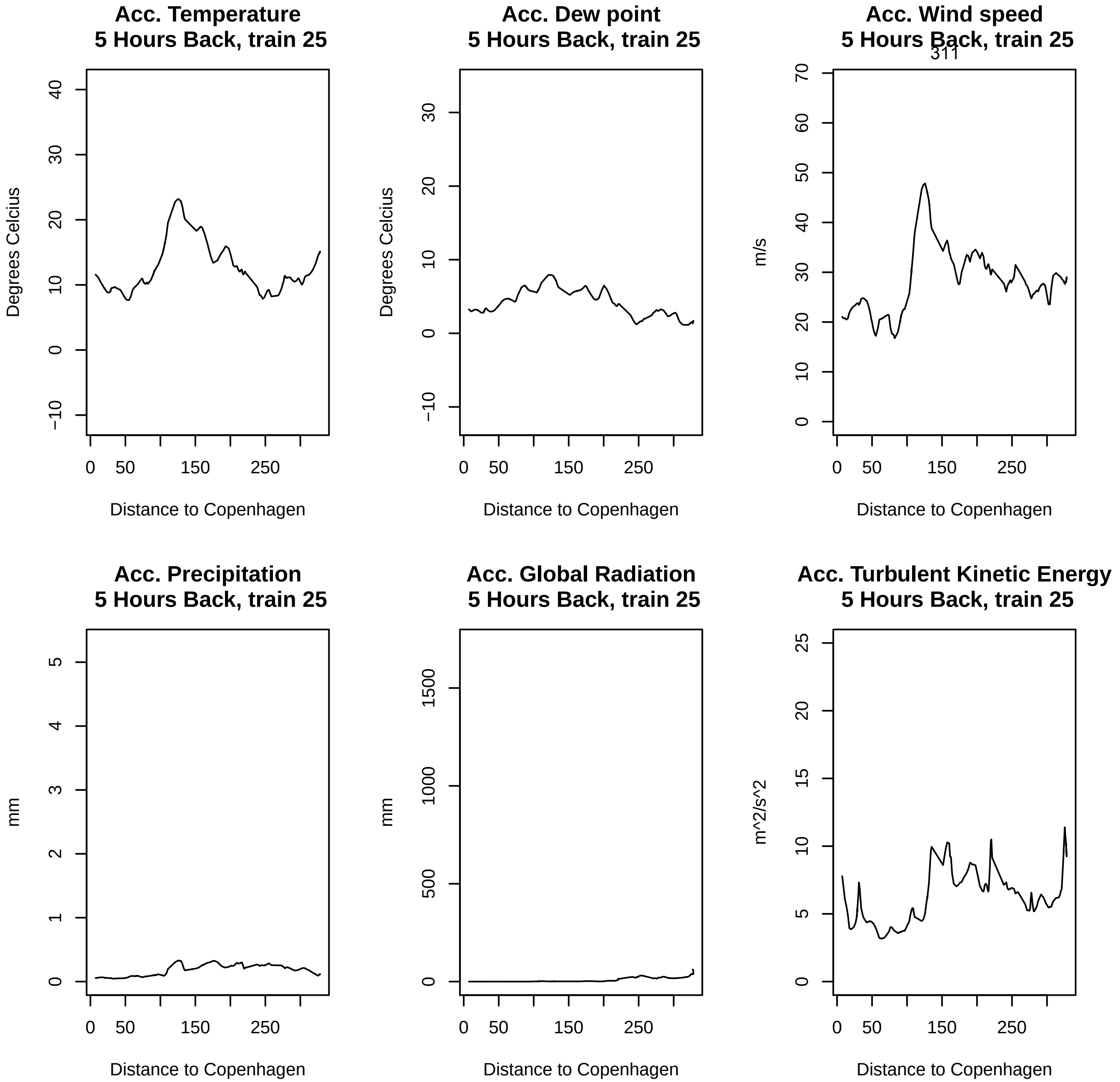

Acc. Temperature
24 Hours Back, train 24
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 24
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 24
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 24
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 24
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 24
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

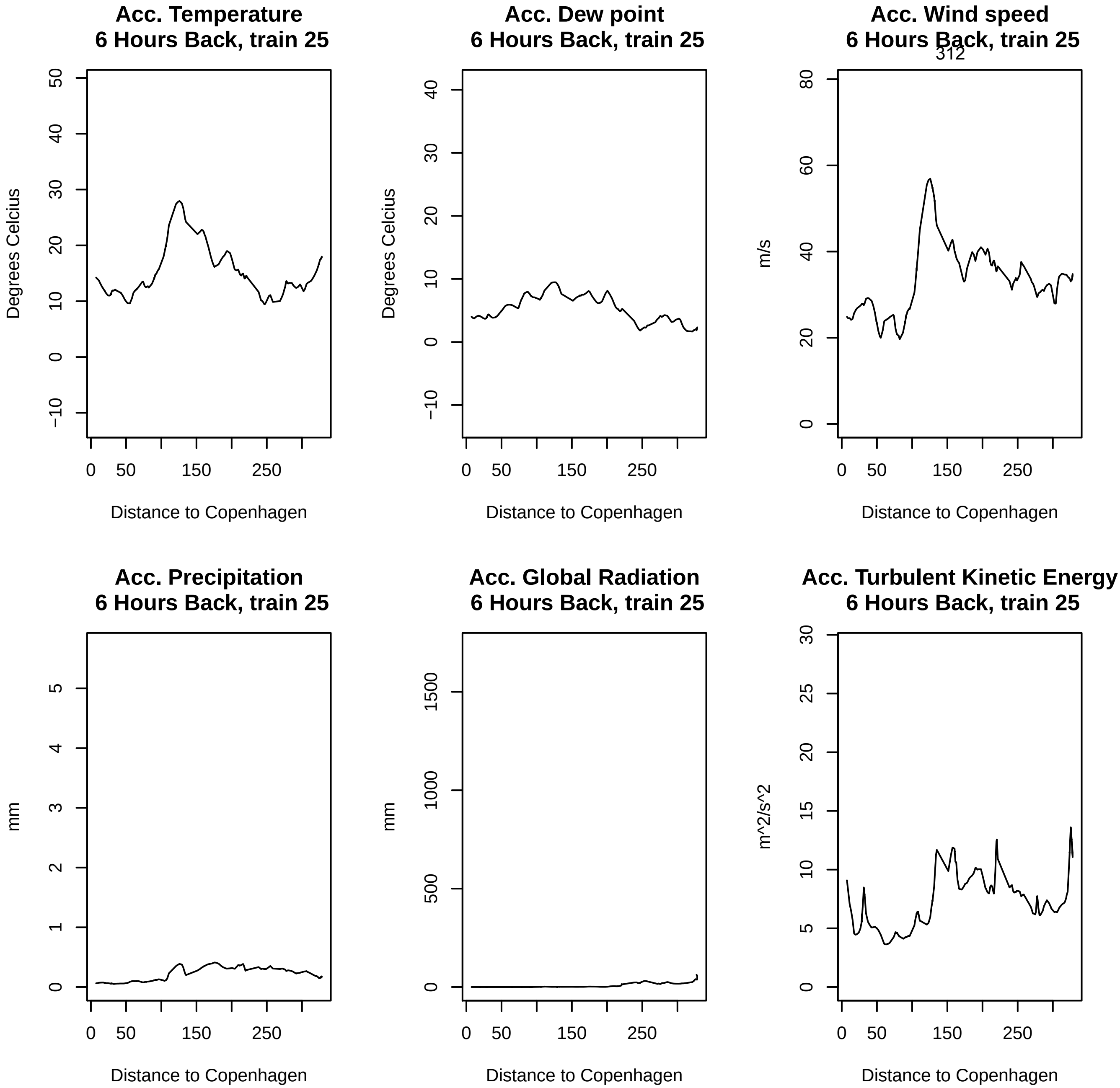

Temperature, train 25
Degrees Celcius
Distance to Copenhagen
Dew point, train 25
Degrees Celcius
Distance to Copenhagen
Wind speed, train 25
m/s
Distance to Copenhagen
Precipitation, train 25
mm
Distance to Copenhagen
Global Radiation, train 25
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 25
m^2/s^2
Distance to Copenhagen



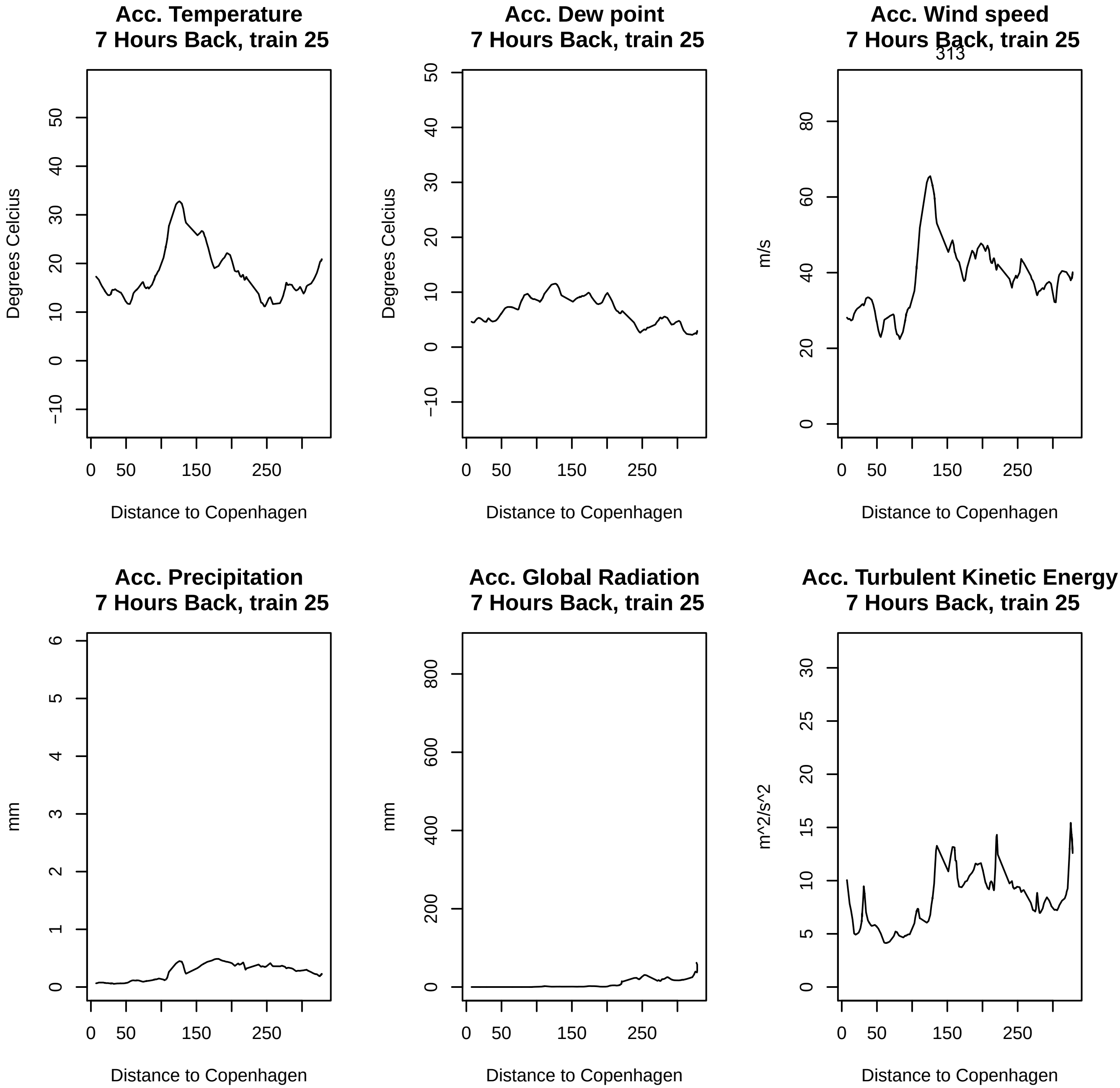
Acc. Temperature
3 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 25
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 25
m^2/s^2
Distance to Copenhagen

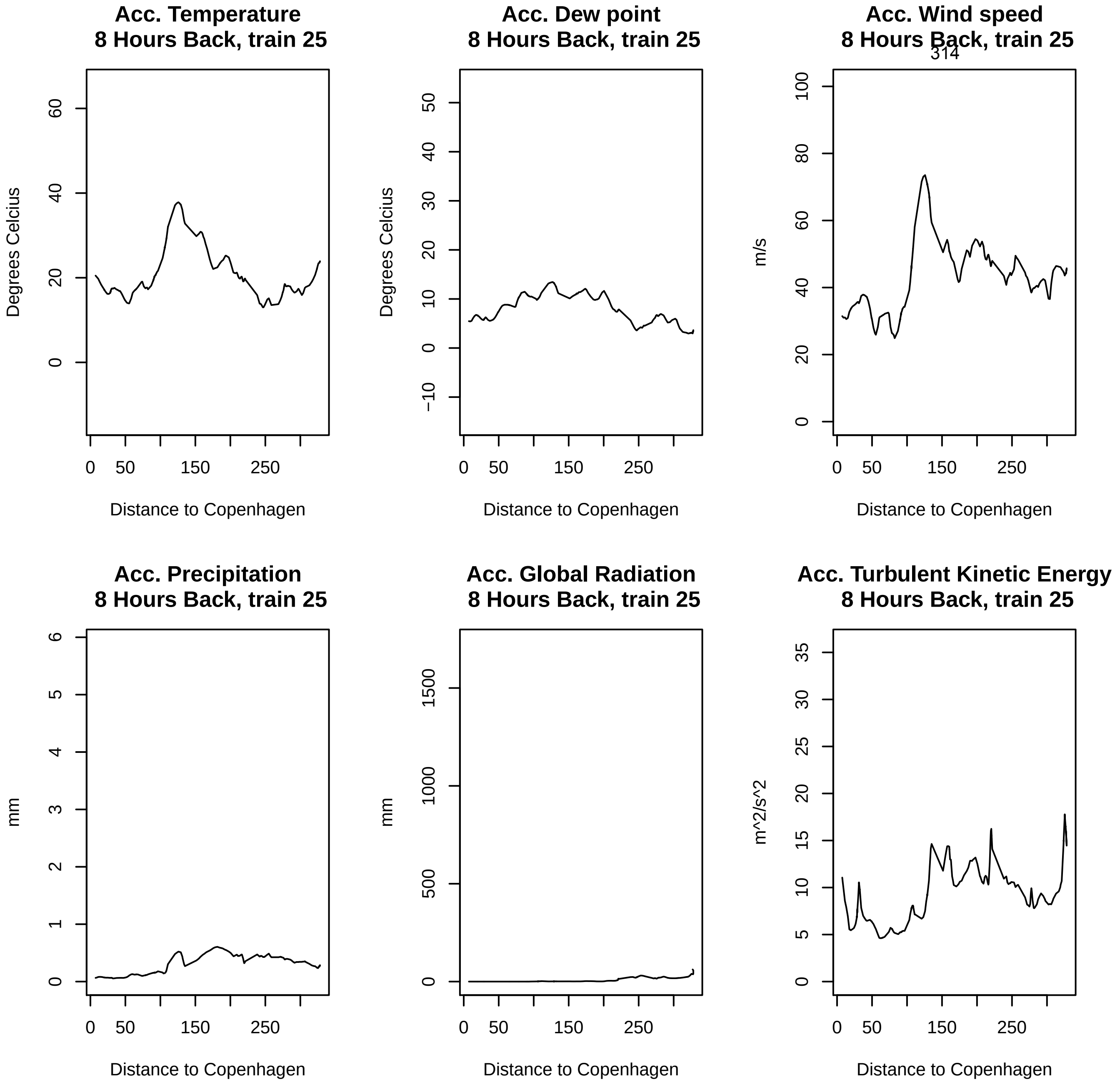

Acc. Temperature
4 Hours Back, train 25
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 25
Degrees Celcius
−10
0
10
20
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 25
m/s
0
10
20
30
40
50
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 25
mm
0
1
2
3
4
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 25
mm
0
500
1000
1500
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 25
m^2/s^2
0
5
10
15
20
Distance to Copenhagen

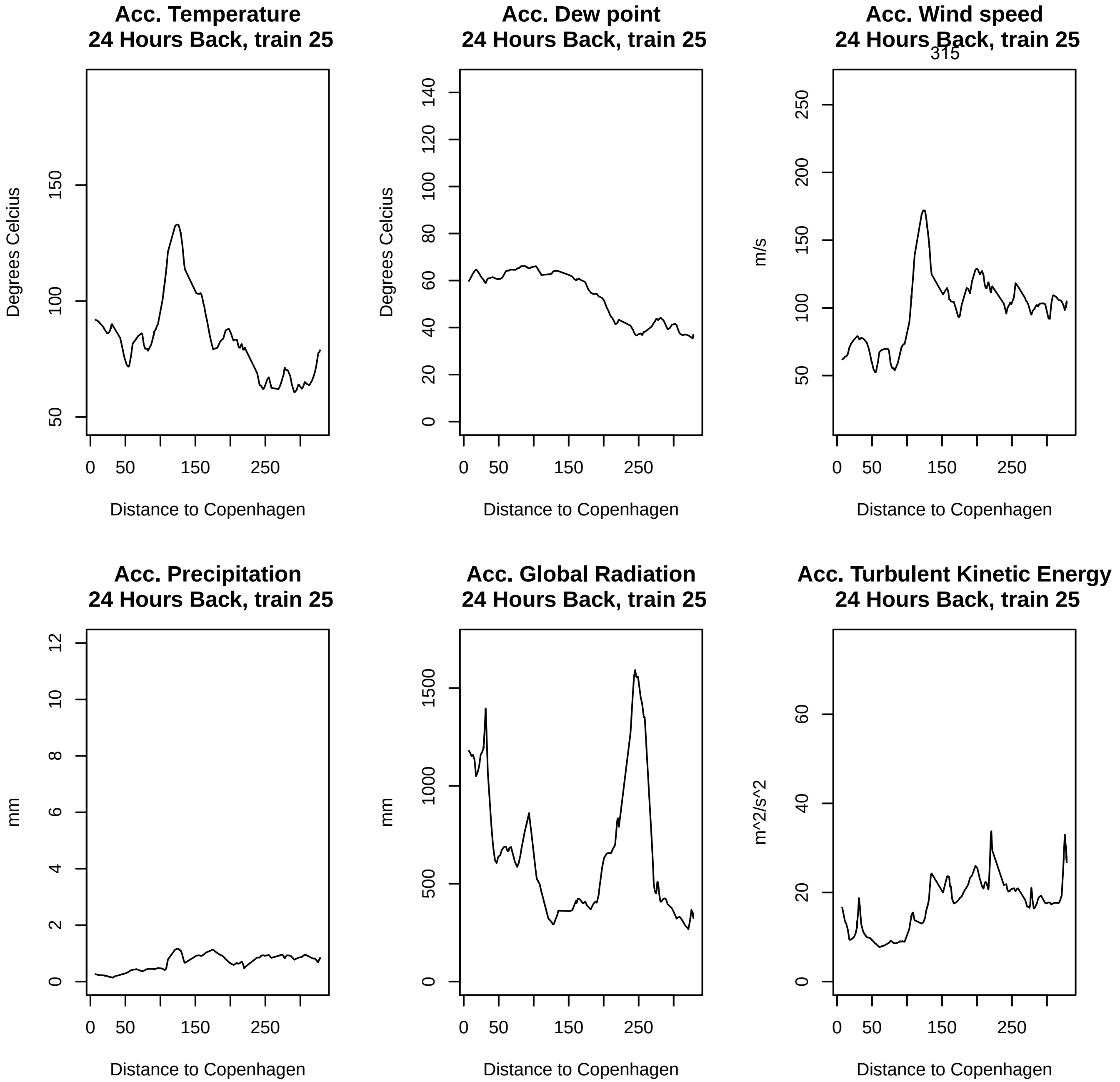

Acc. Temperature
5 Hours Back, train 25
Degrees Celcius
−10 0 10 20 30 40
0 50 150 250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 25
Degrees Celcius
−10 0 10 20 30
0 50 150 250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 25
m/s
0 10 20 30 40 50 60 70
0 50 150 250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 25
mm
0 1 2 3 4 5
0 50 150 250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 25
mm
0 500 1000 1500
0 50 150 250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 25
m^2/s^2
0 5 10 15 20 25
0 50 150 250
Distance to Copenhagen

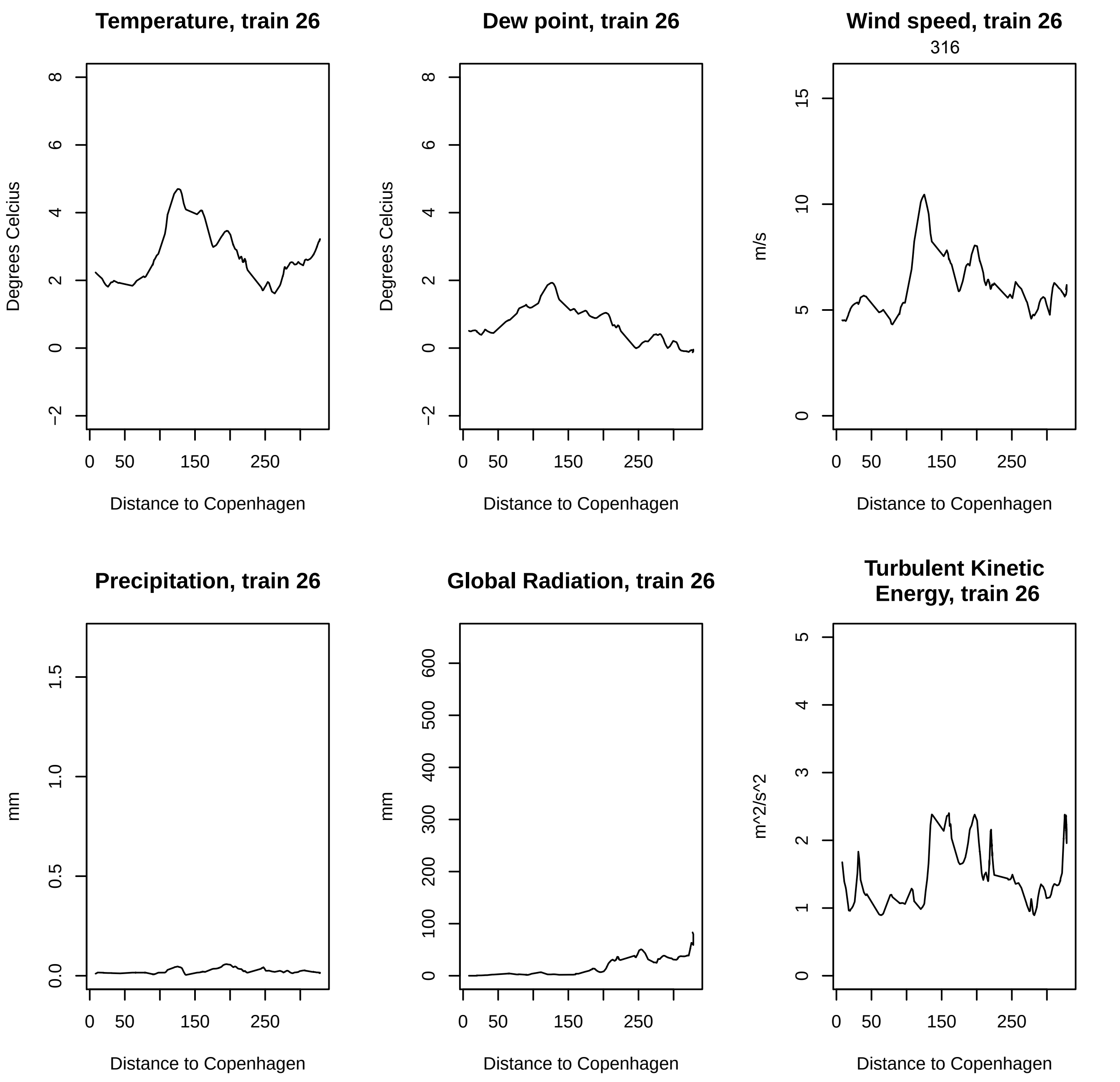


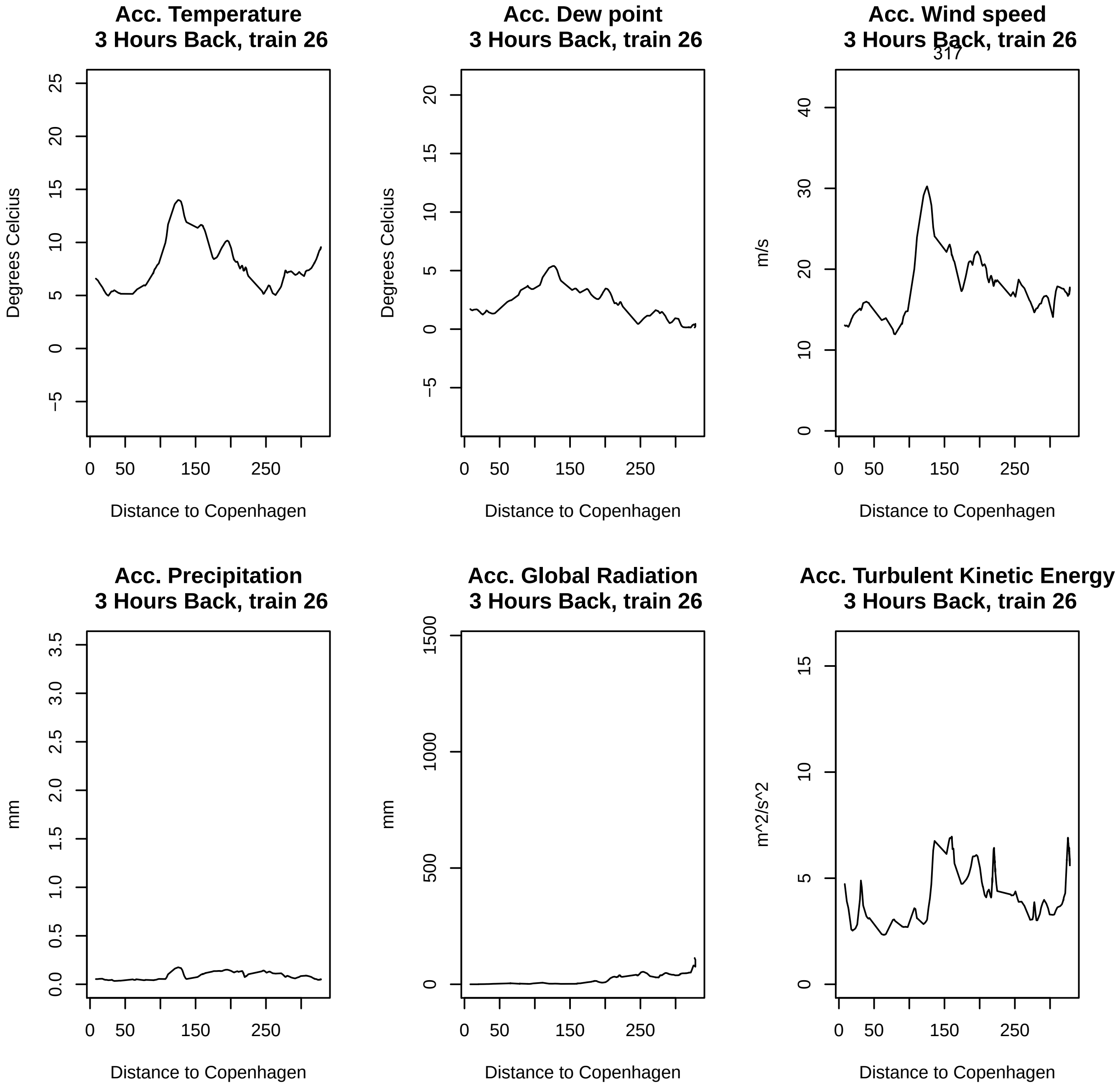
Acc. Temperature
6 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 25
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 25
m^2/s^2
Distance to Copenhagen

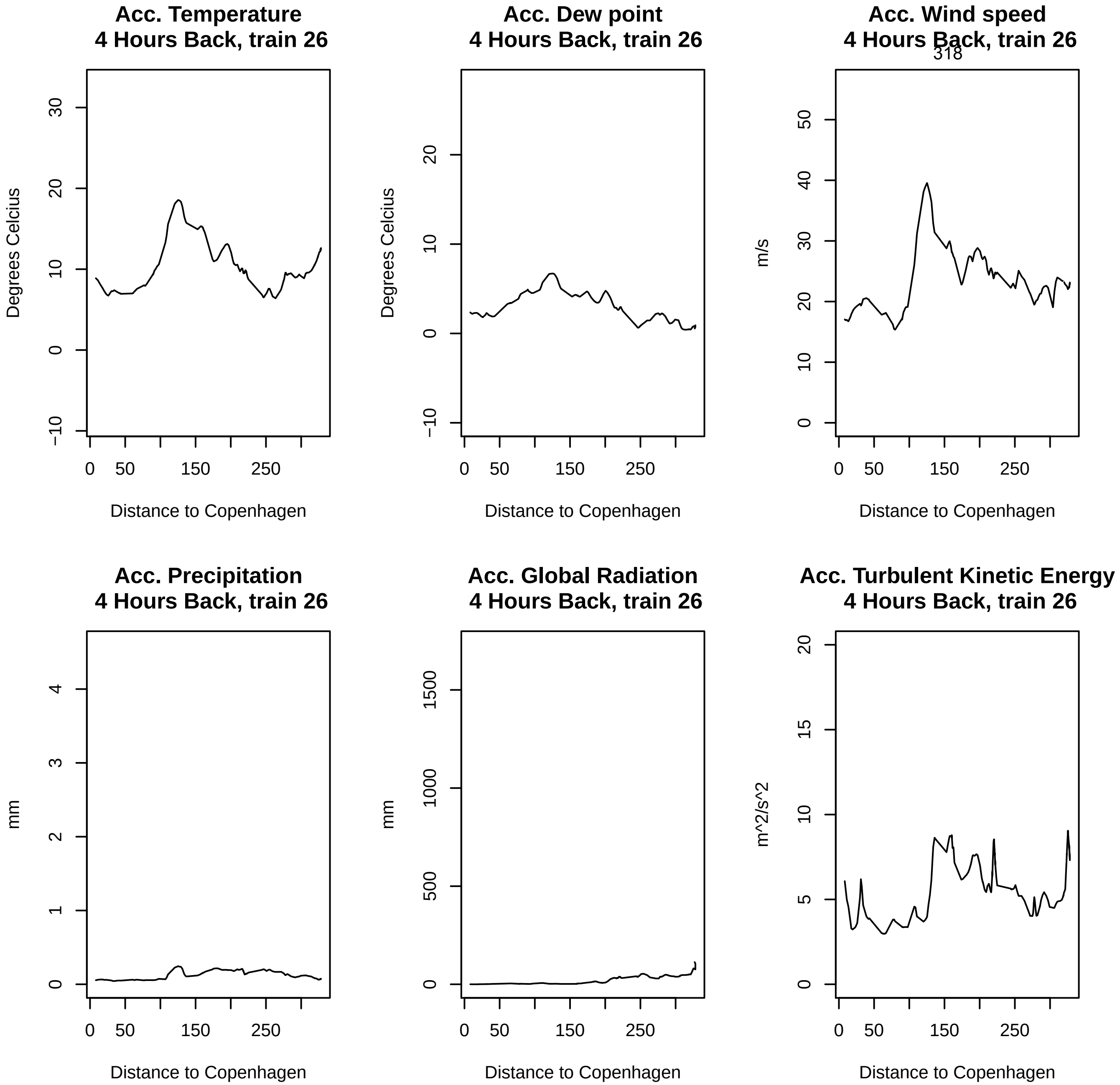

Acc. Temperature
7 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 25
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 25
m^2/s^2
Distance to Copenhagen

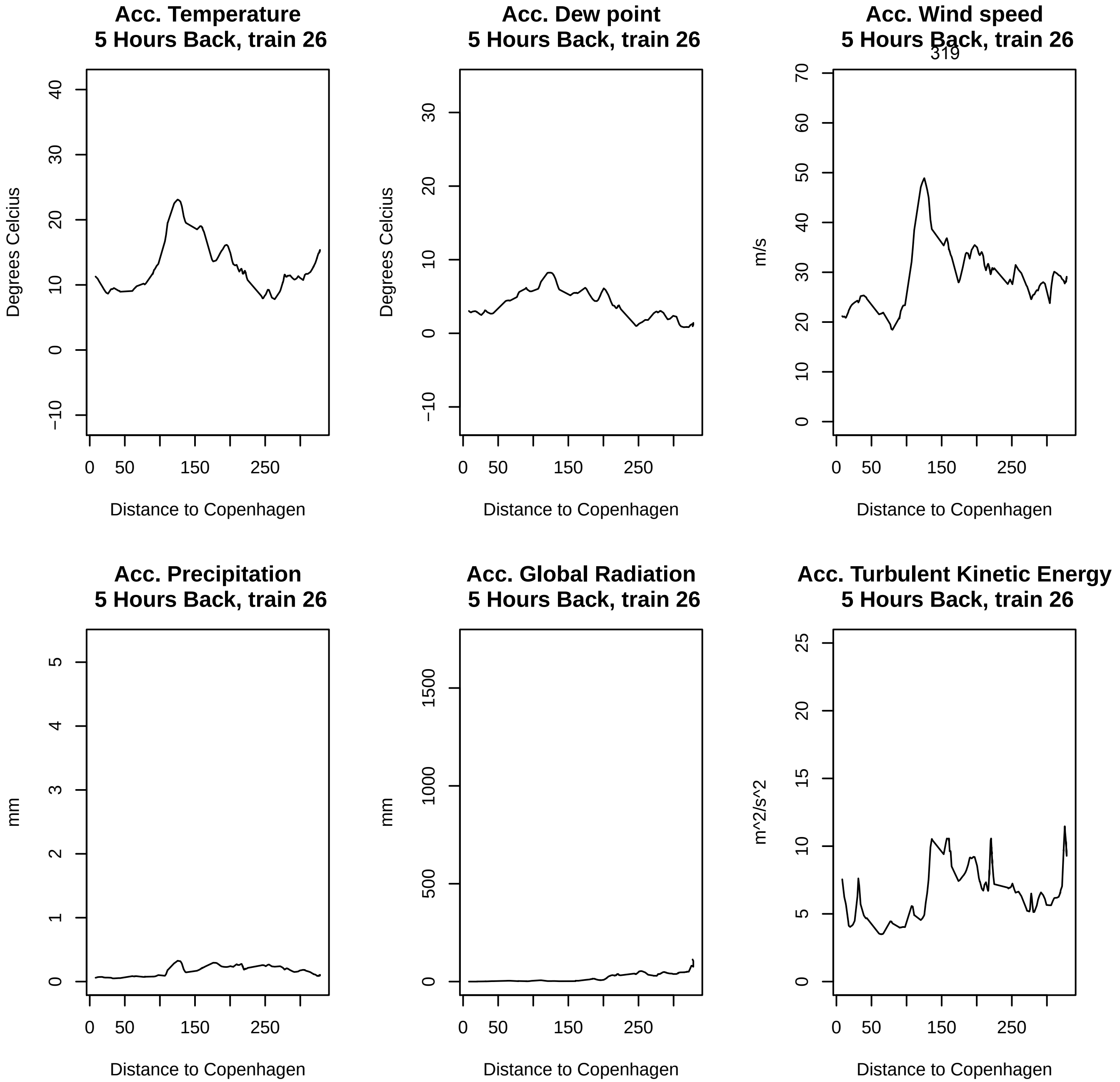

Acc. Temperature
8 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 25
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 25
m^2/s^2
Distance to Copenhagen

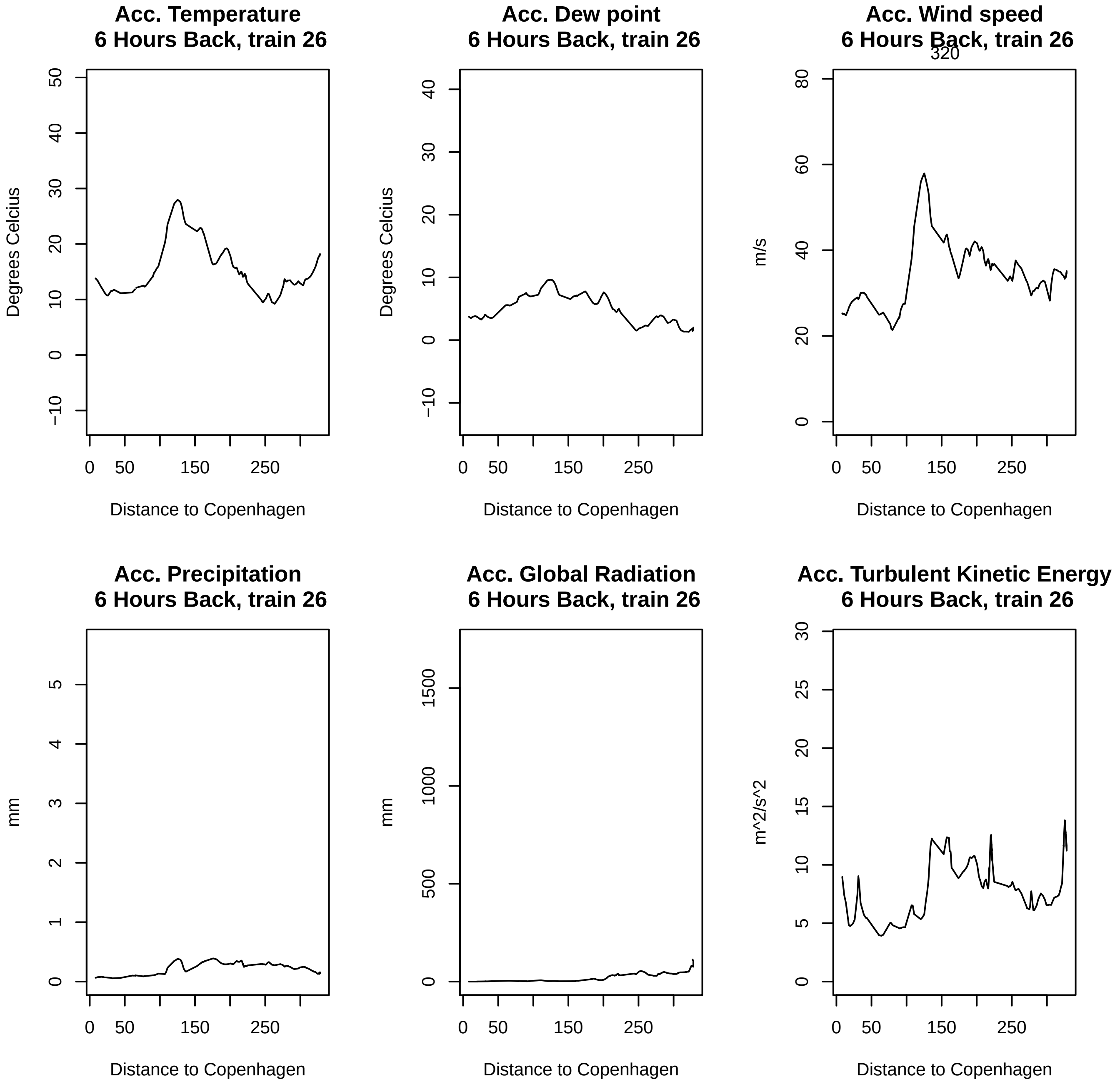

Acc. Temperature
24 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 25
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 25
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 25
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 25
m^2/s^2
Distance to Copenhagen

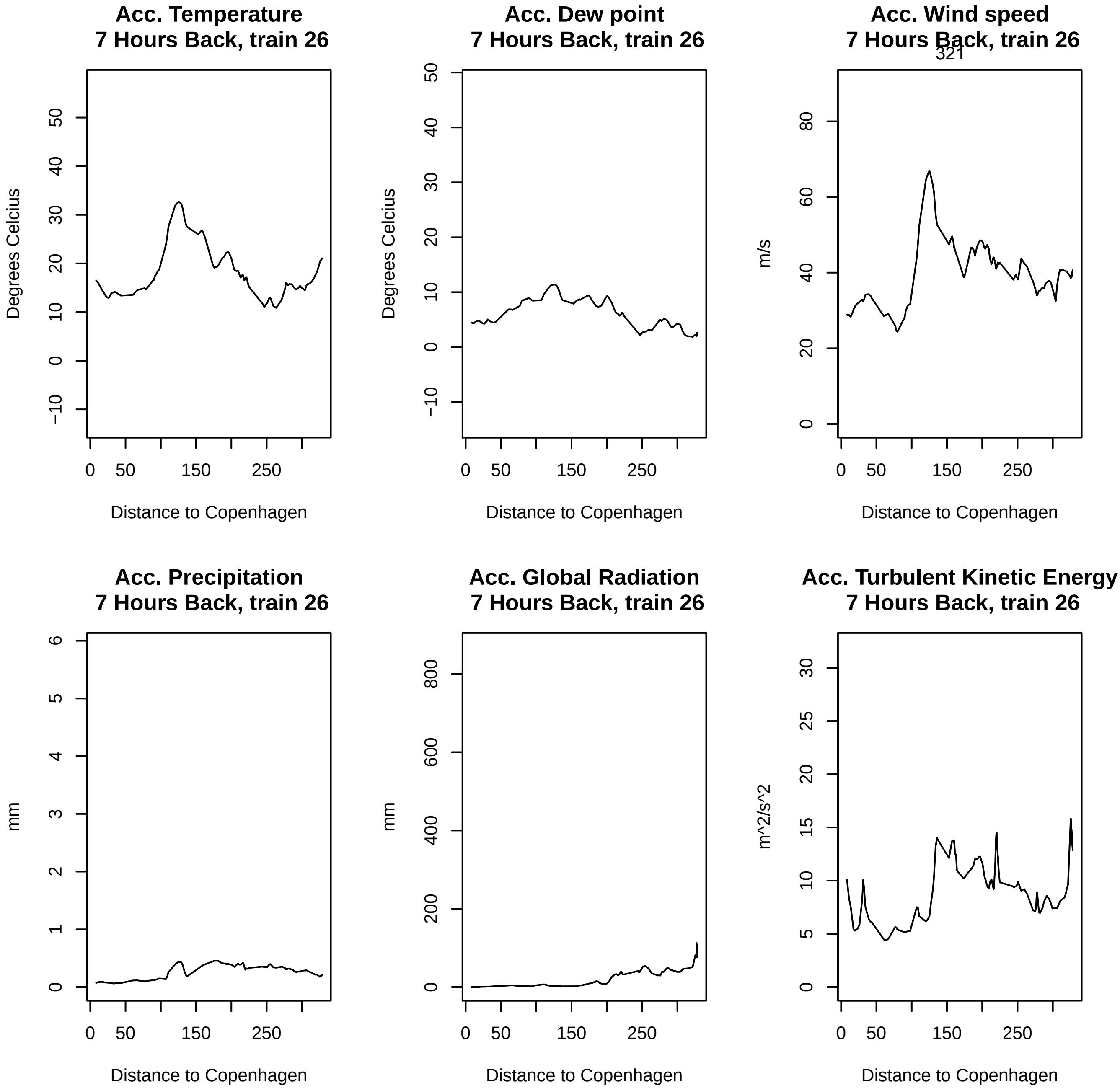

Temperature, train 26
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Dew point, train 26
Degrees Celcius
−2
0
2
4
6
8
0
50
150
250
Distance to Copenhagen
Wind speed, train 26
316
m/s
0
5
10
15
0
50
150
250
Distance to Copenhagen
Precipitation, train 26
mm
0.0
0.5
1.0
1.5
0
50
150
250
Distance to Copenhagen
Global Radiation, train 26
mm
0
100
200
300
400
500
600
0
50
150
250
Distance to Copenhagen
Turbulent Kinetic Energy, train 26
m^2/s^2
0
1
2
3
4
5
0
50
150
250
Distance to Copenhagen


Acc. Temperature
3 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 26
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 26
m^2/s^2
Distance to Copenhagen

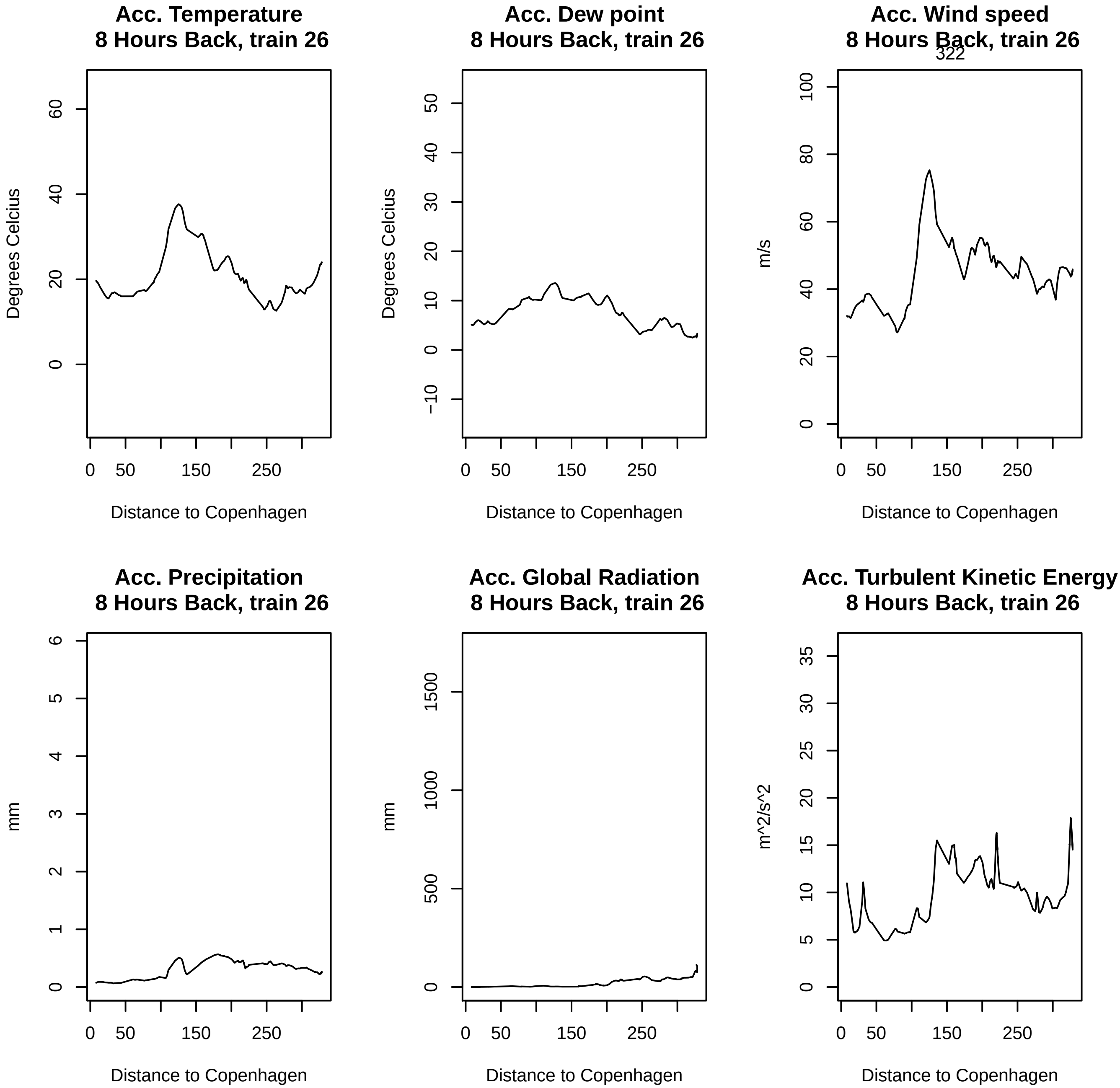

Acc. Temperature
4 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 26
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 26
m^2/s^2
Distance to Copenhagen

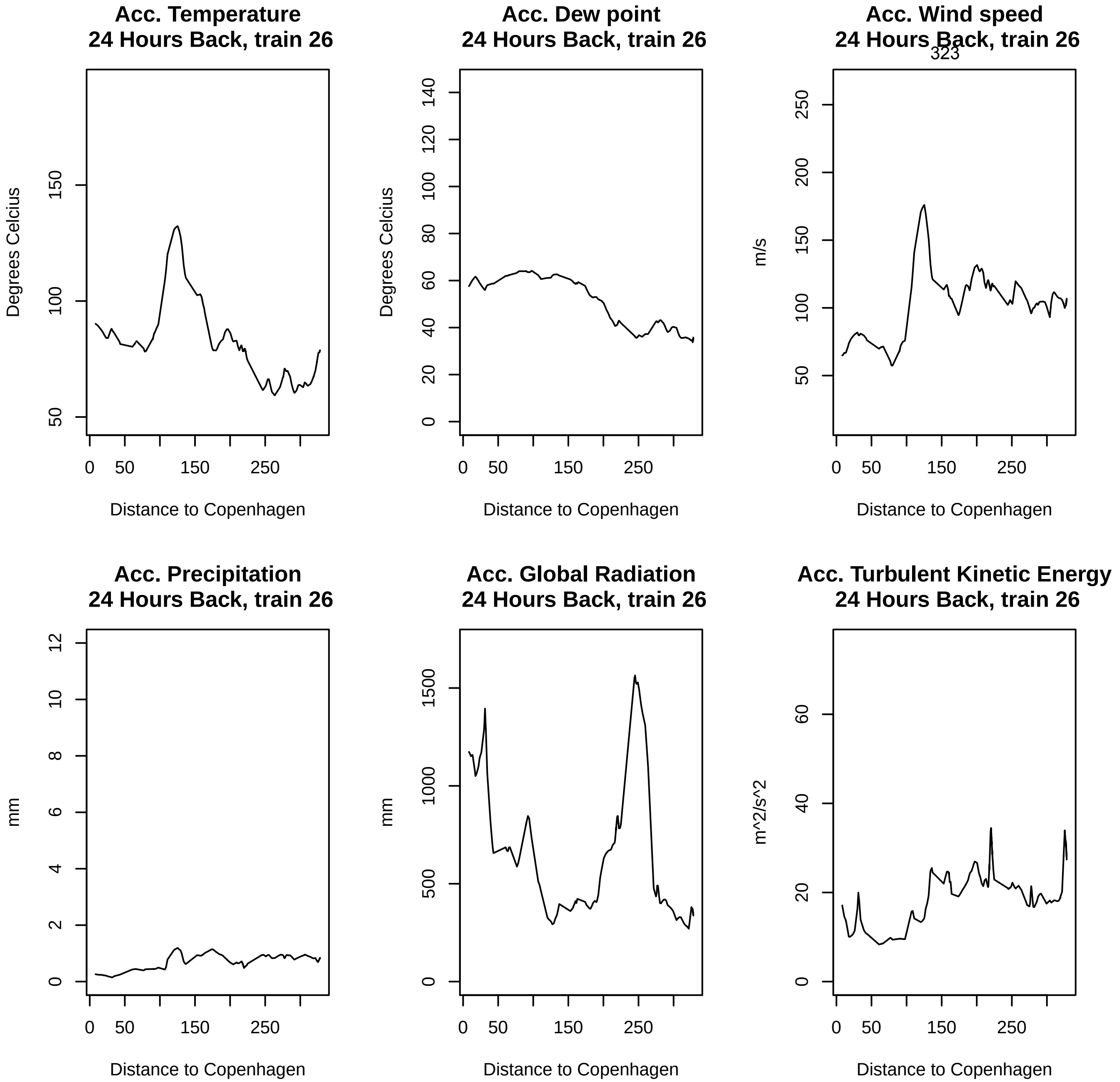

Acc. Temperature
5 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 26
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 26
m^2/s^2
Distance to Copenhagen

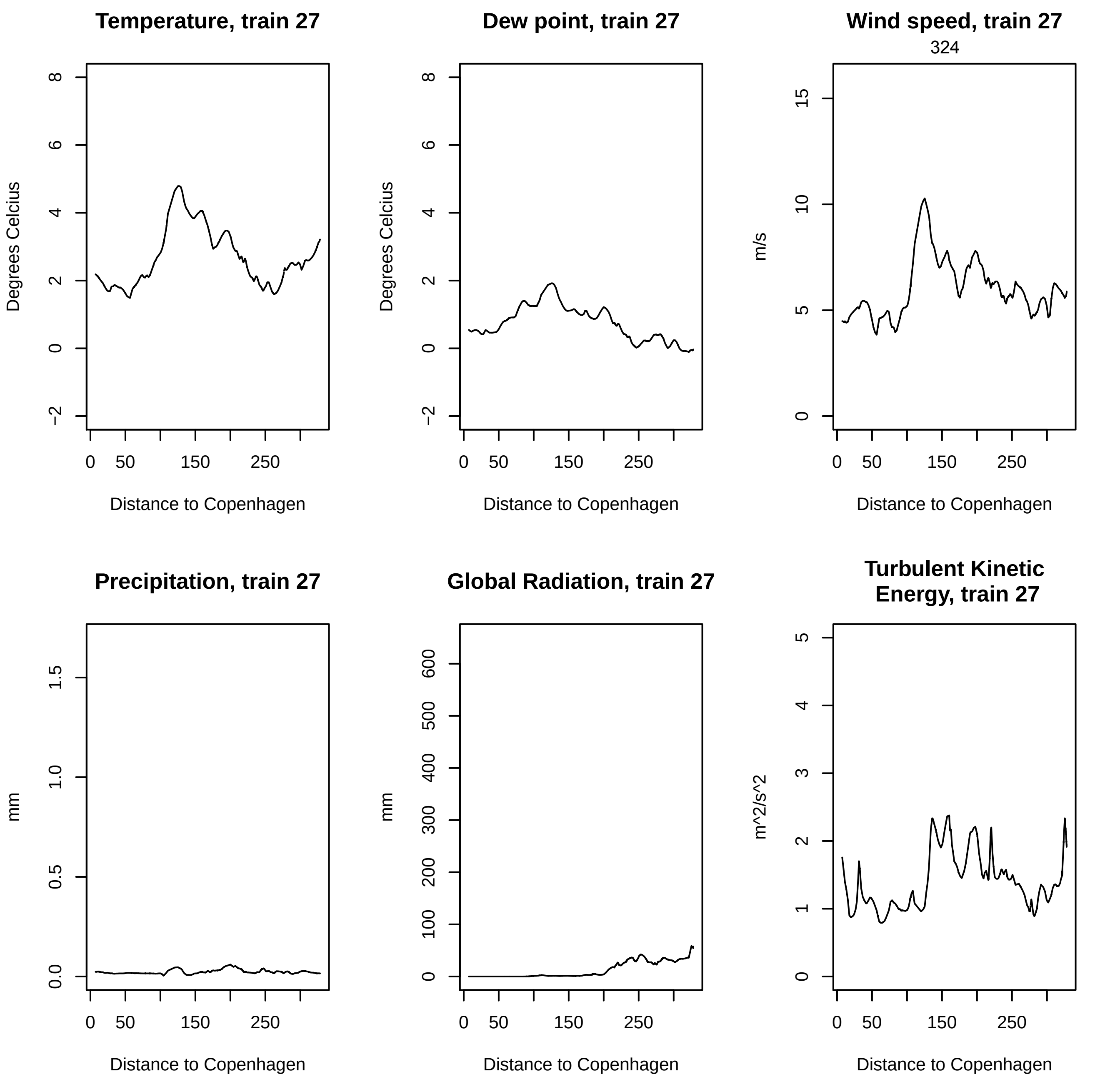

Acc. Temperature
6 Hours Back, train 26
Degrees Celcius
−10
0
10
20
30
40
50
Distance to Copenhagen
0
50
150
250
Acc. Dew point
6 Hours Back, train 26
Degrees Celcius
−10
0
10
20
30
40
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
6 Hours Back, train 26
m/s
0
20
40
60
80
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
6 Hours Back, train 26
mm
0
1
2
3
4
5
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
6 Hours Back, train 26
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
6 Hours Back, train 26
m^2/s^2
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250

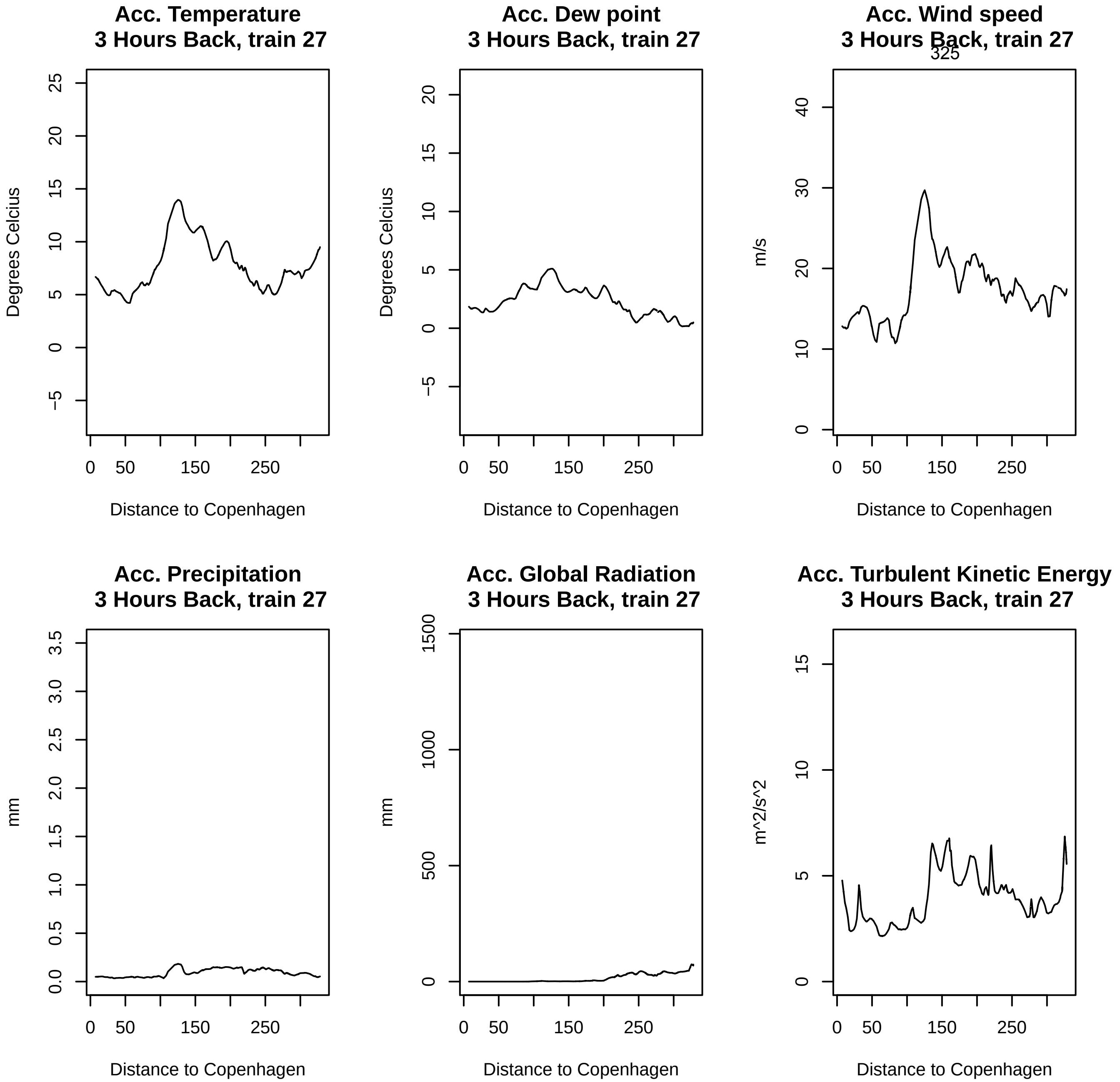


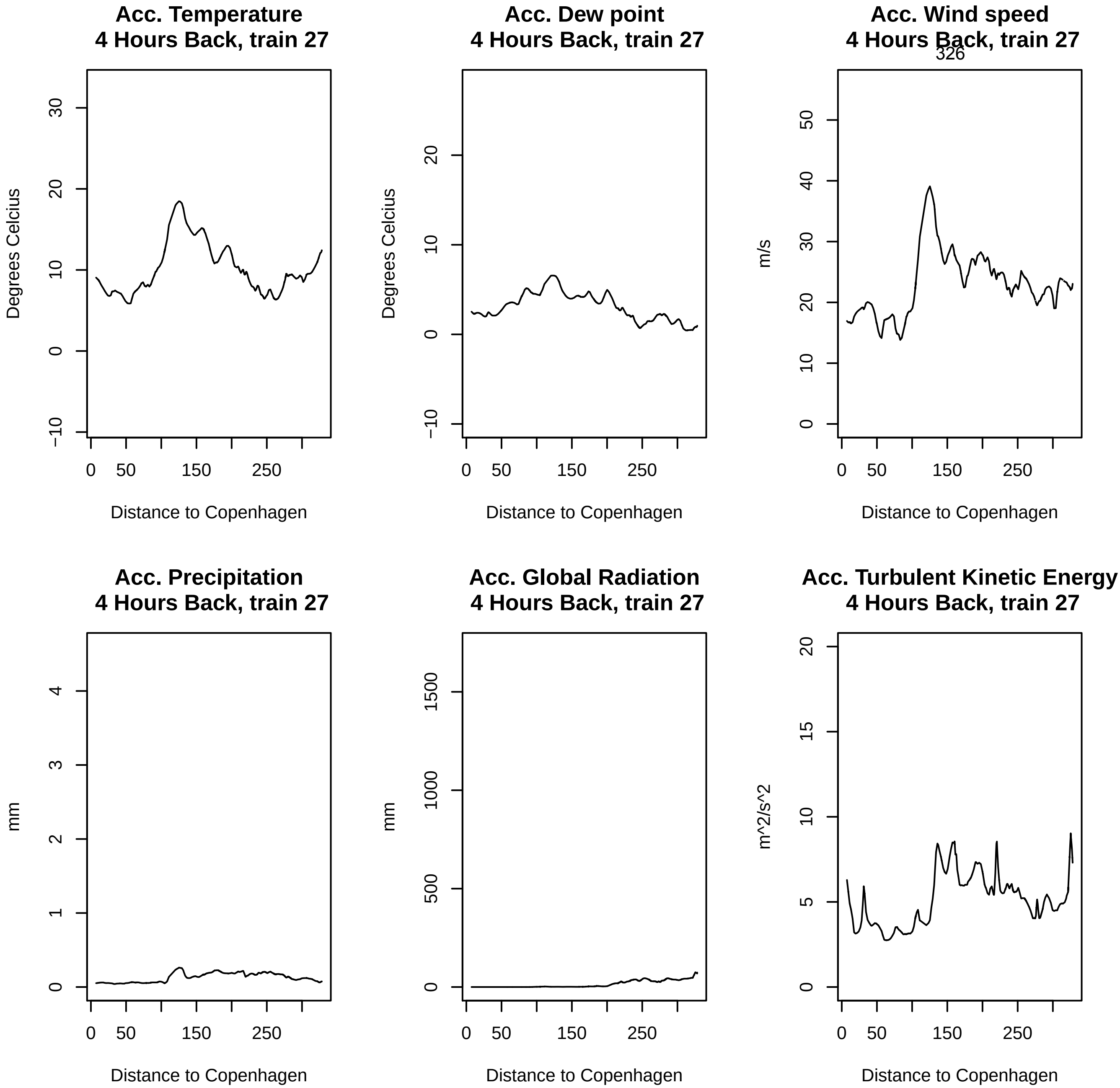
Acc. Temperature
7 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 26
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 26
m^2/s^2
Distance to Copenhagen

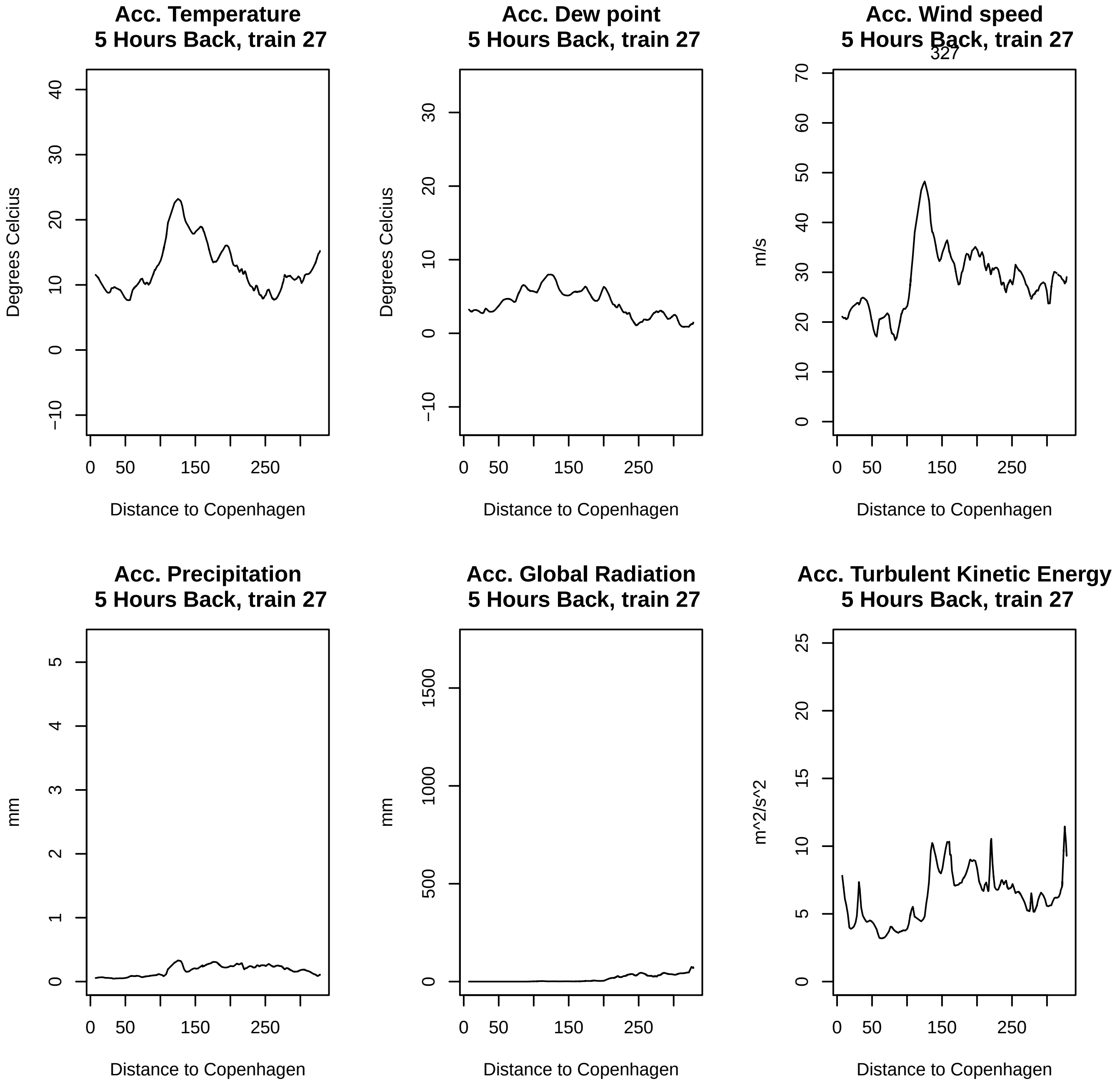

Acc. Temperature
8 Hours Back, train 26
Degrees Celcius
60
40
20
0
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 26
Degrees Celcius
50
40
30
20
10
0
−10
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 26
m/s
100
80
60
40
20
0
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 26
mm
6
5
4
3
2
1
0
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 26
mm
1500
1000
500
0
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 26
m^2/s^2
35
30
25
20
15
10
5
0
0
50
150
250
Distance to Copenhagen

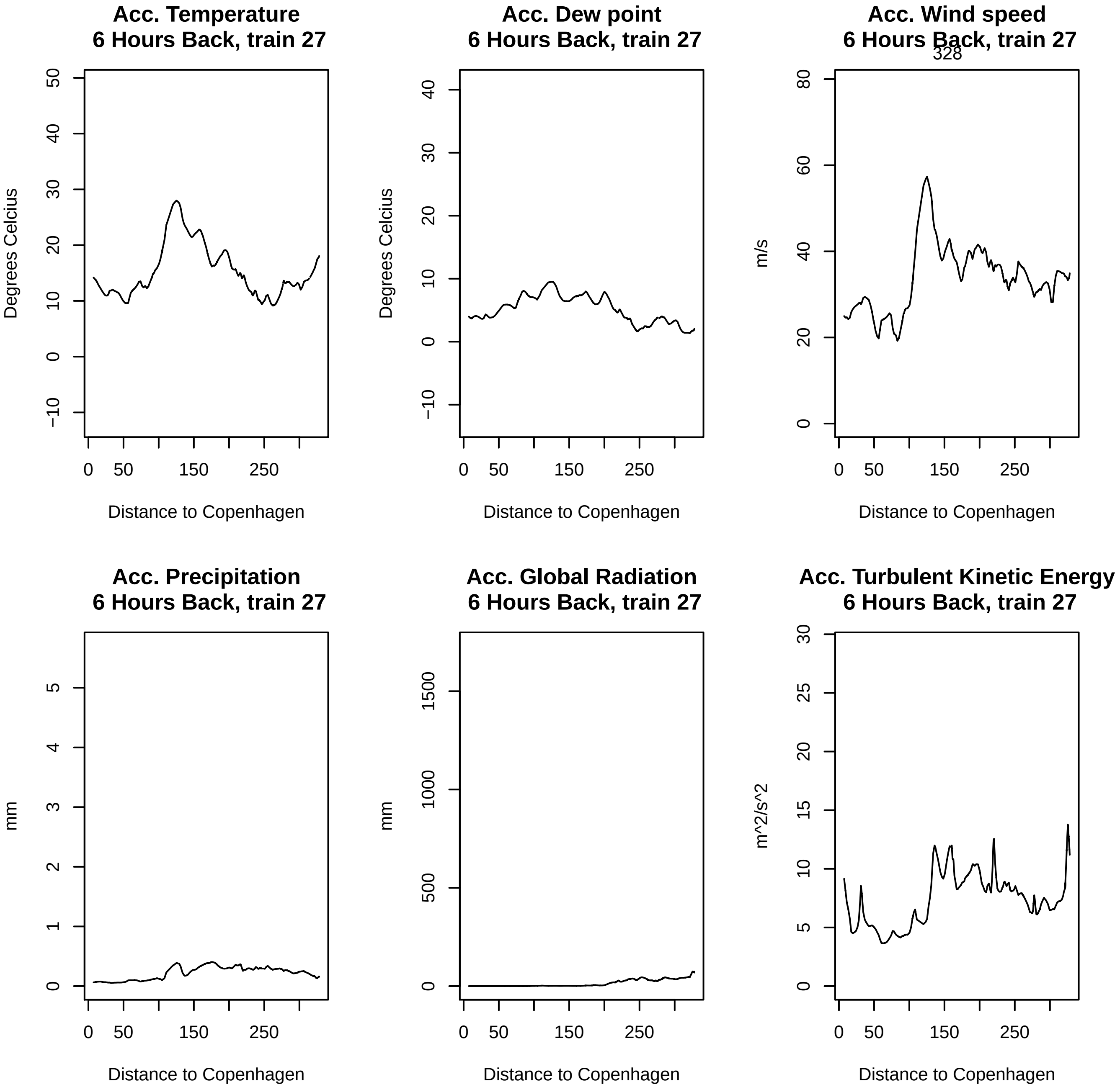

Acc. Temperature
24 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 26
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 26
m/s
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 26
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 26
m^2/s^2
Distance to Copenhagen


Temperature, train 27
Degrees Celcius
Distance to Copenhagen
Dew point, train 27
Degrees Celcius
Distance to Copenhagen
Wind speed, train 27
324
m/s
Distance to Copenhagen
Precipitation, train 27
mm
Distance to Copenhagen
Global Radiation, train 27
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 27
m^2/s^2
Distance to Copenhagen

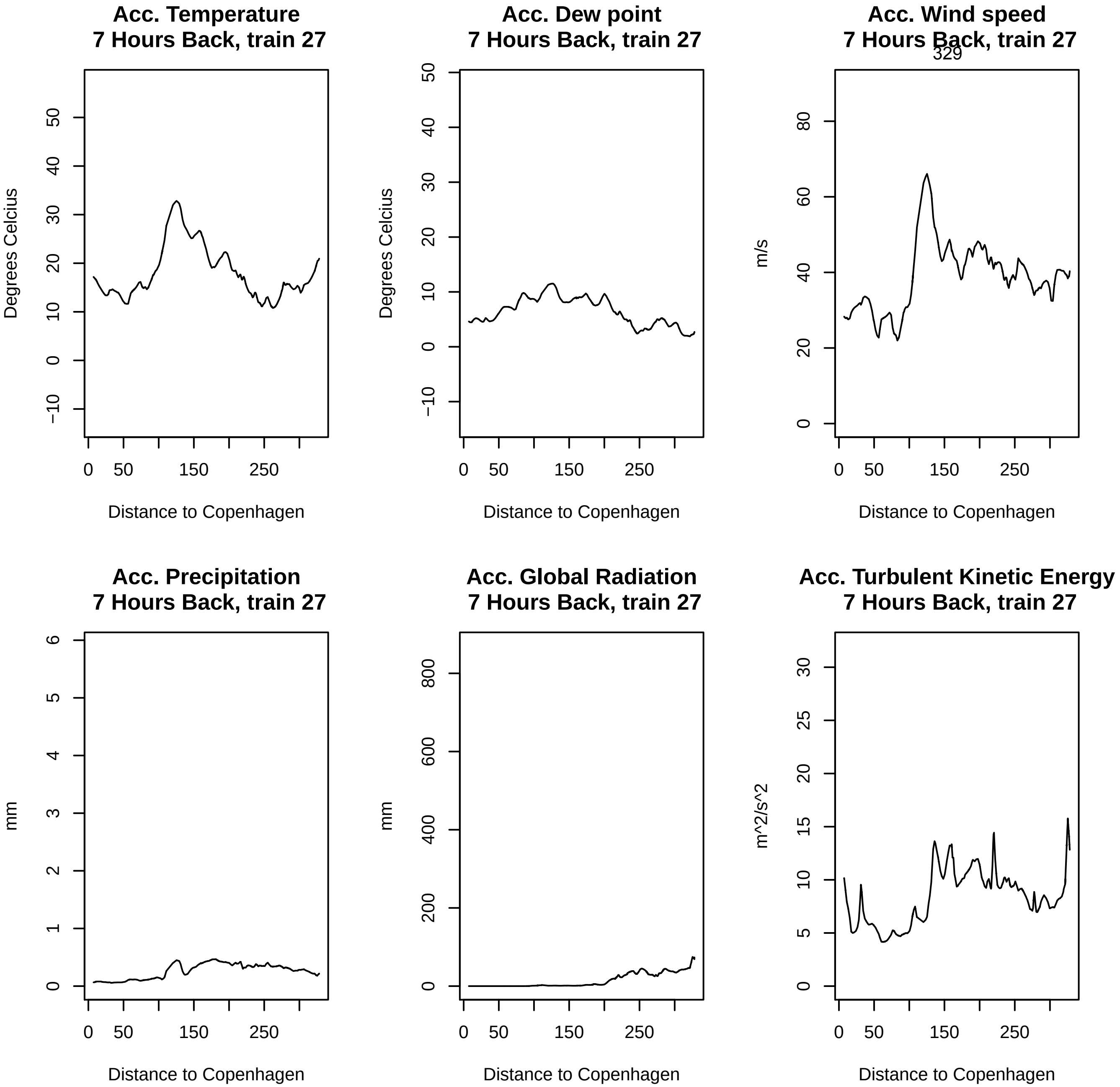

Acc. Temperature
3 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 27
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 27
m^2/s^2
Distance to Copenhagen

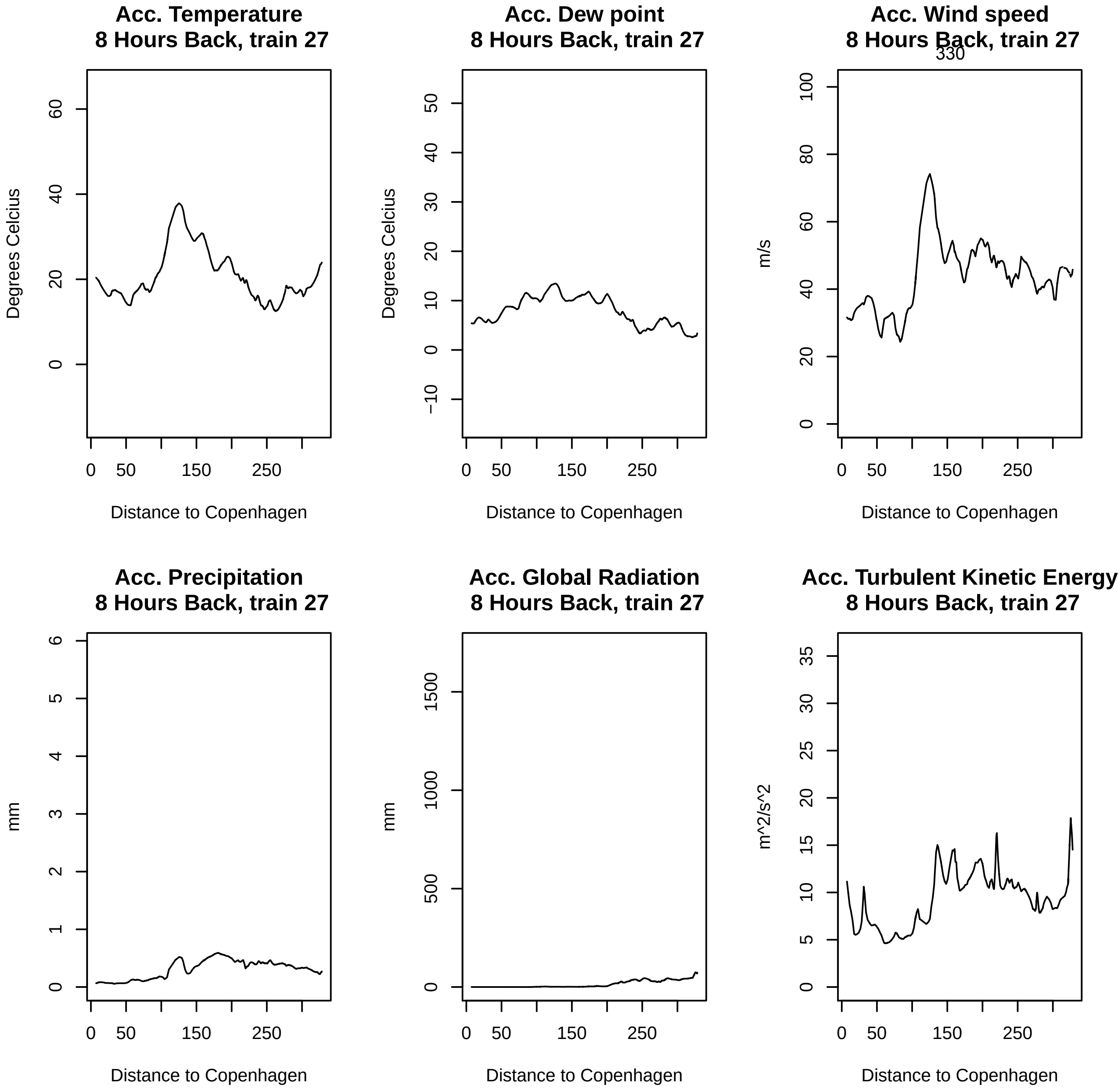

Acc. Temperature
4 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 27
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 27
m^2/s^2
Distance to Copenhagen


Acc. Temperature
5 Hours Back, train 27
Degrees Celcius
40
30
20
10
0
−10
0
50
150
250
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 27
Degrees Celcius
30
20
10
0
−10
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 27
327
m/s
70
60
50
40
30
20
10
0
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 27
mm
5
4
3
2
1
0
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 27
mm
1500
1000
500
0
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 27
m^2/s^2
25
20
15
10
5
0
0
50
150
250
Distance to Copenhagen

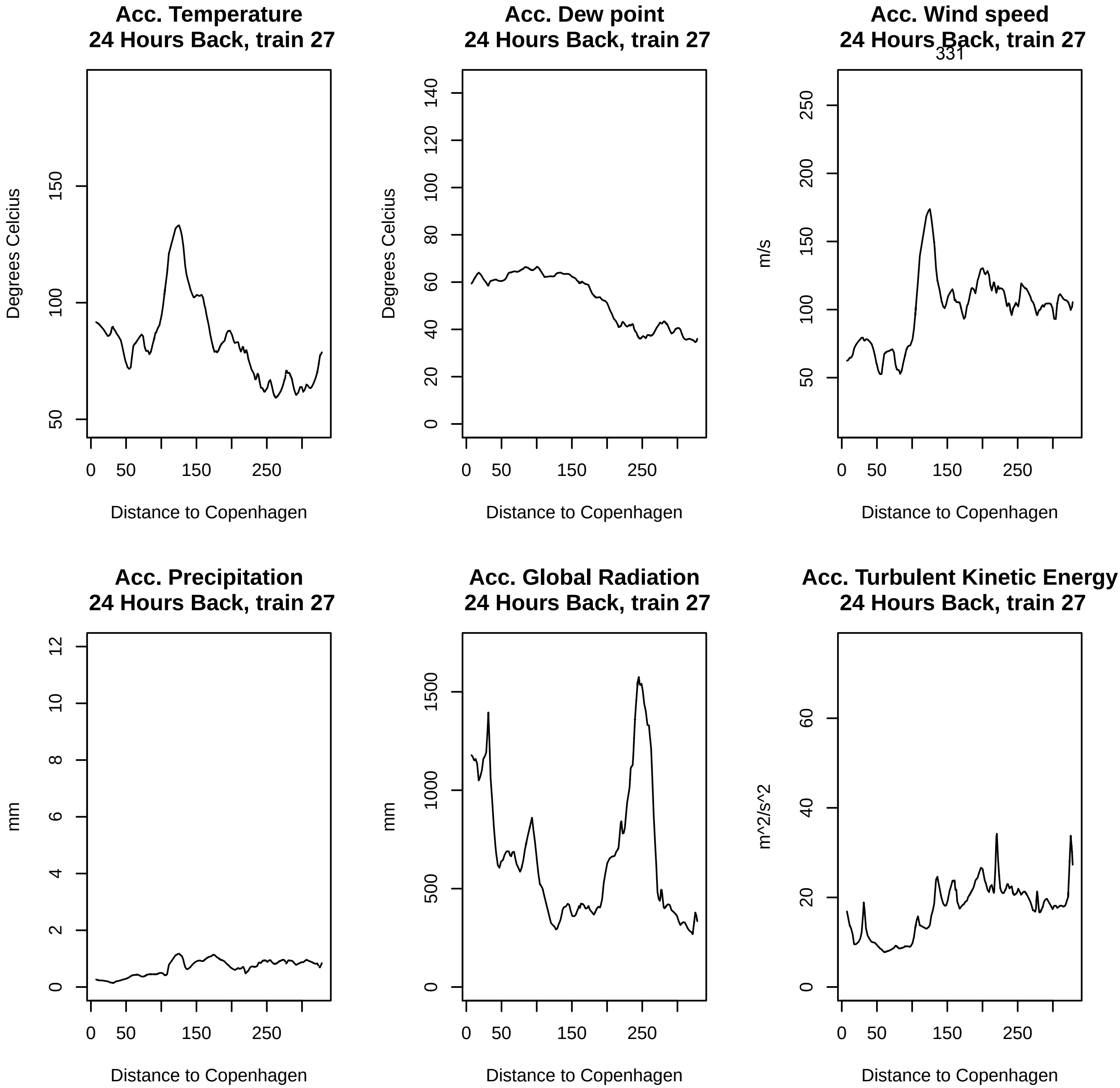


Acc. Temperature
6 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 27
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 27
m^2/s^2
Distance to Copenhagen

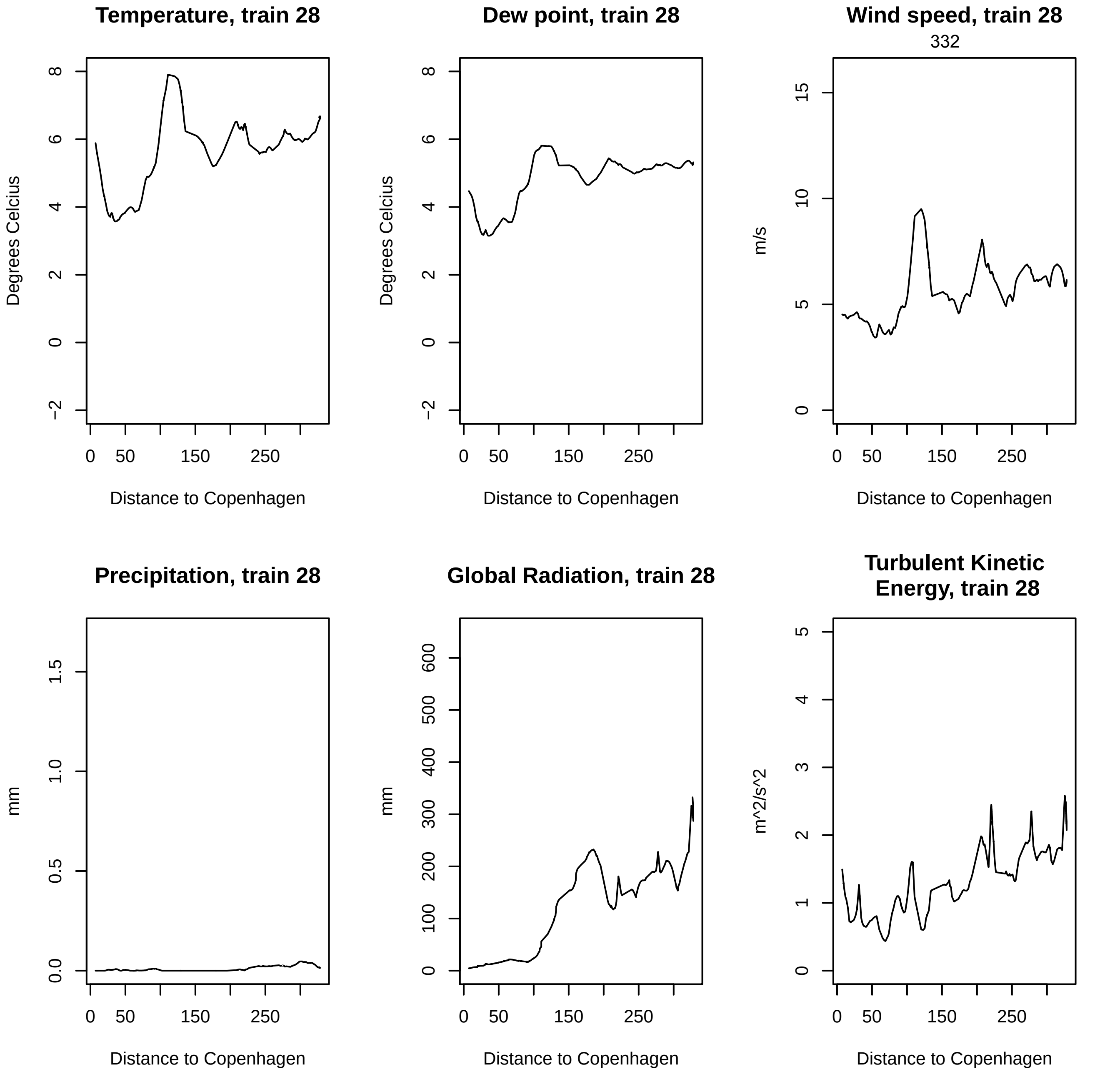

Acc. Temperature
7 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 27
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 27
m^2/s^2
Distance to Copenhagen

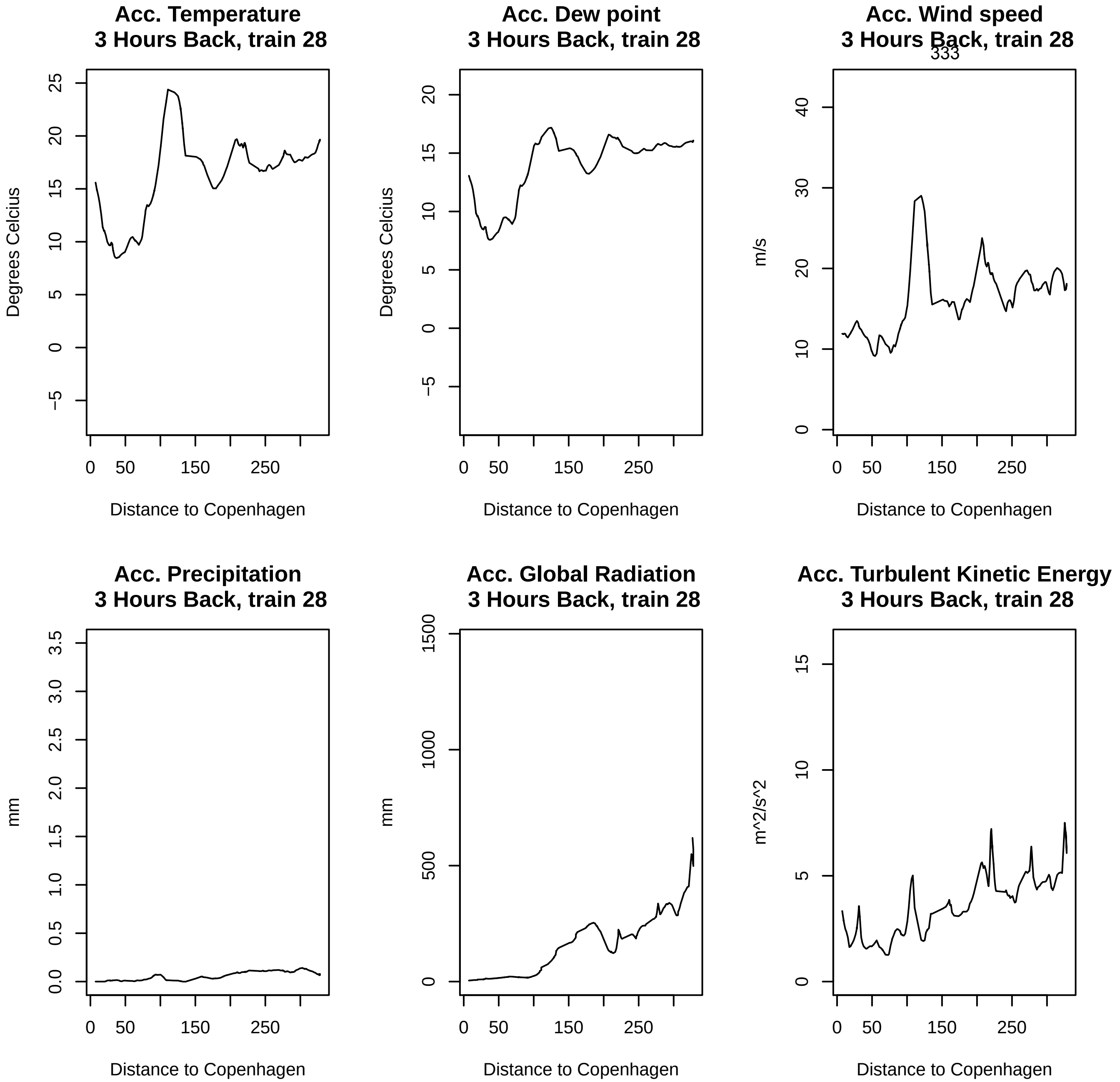


Acc. Temperature
8 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 27
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 27
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 27
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 27
m^2/s^2
Distance to Copenhagen

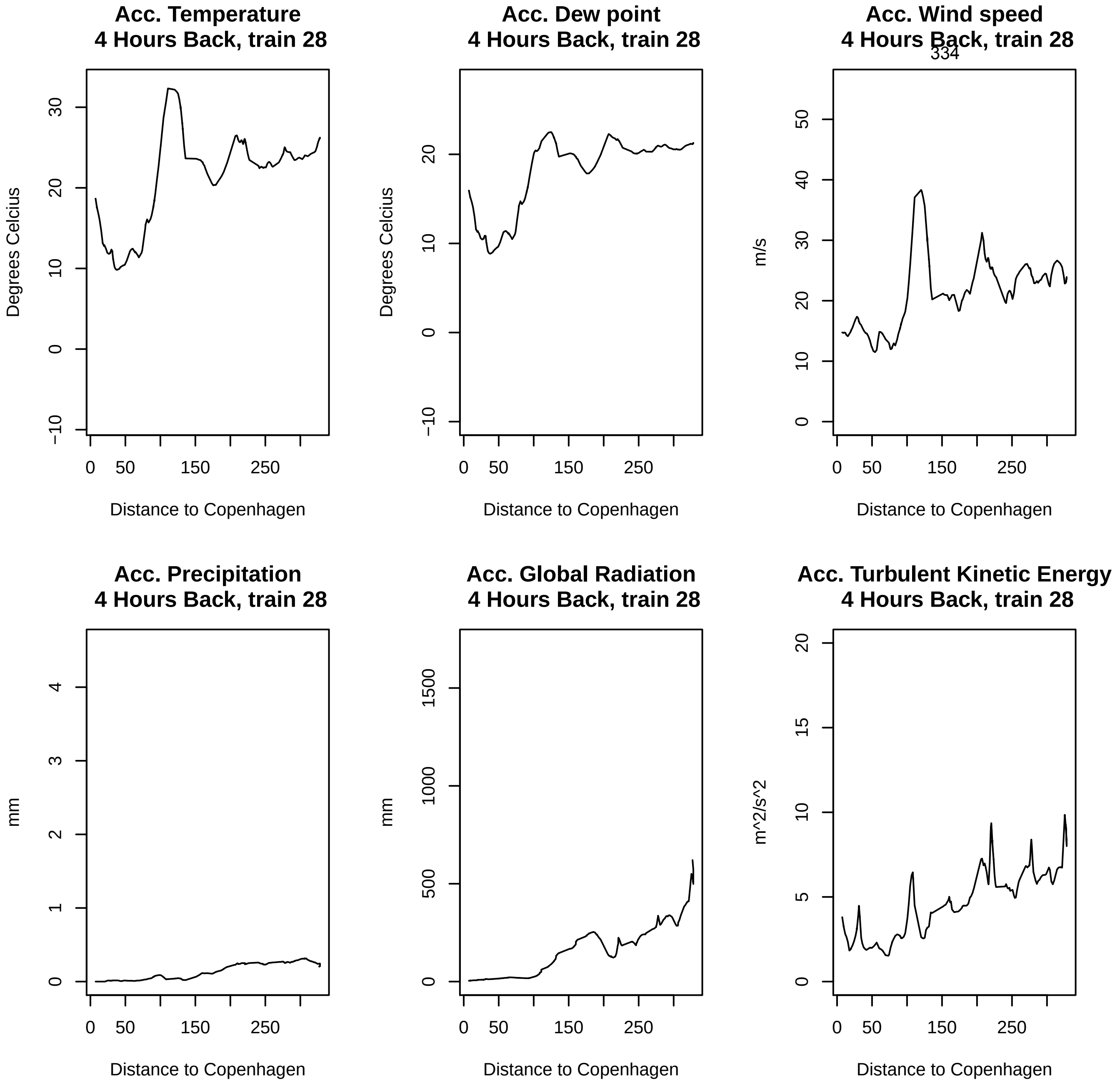


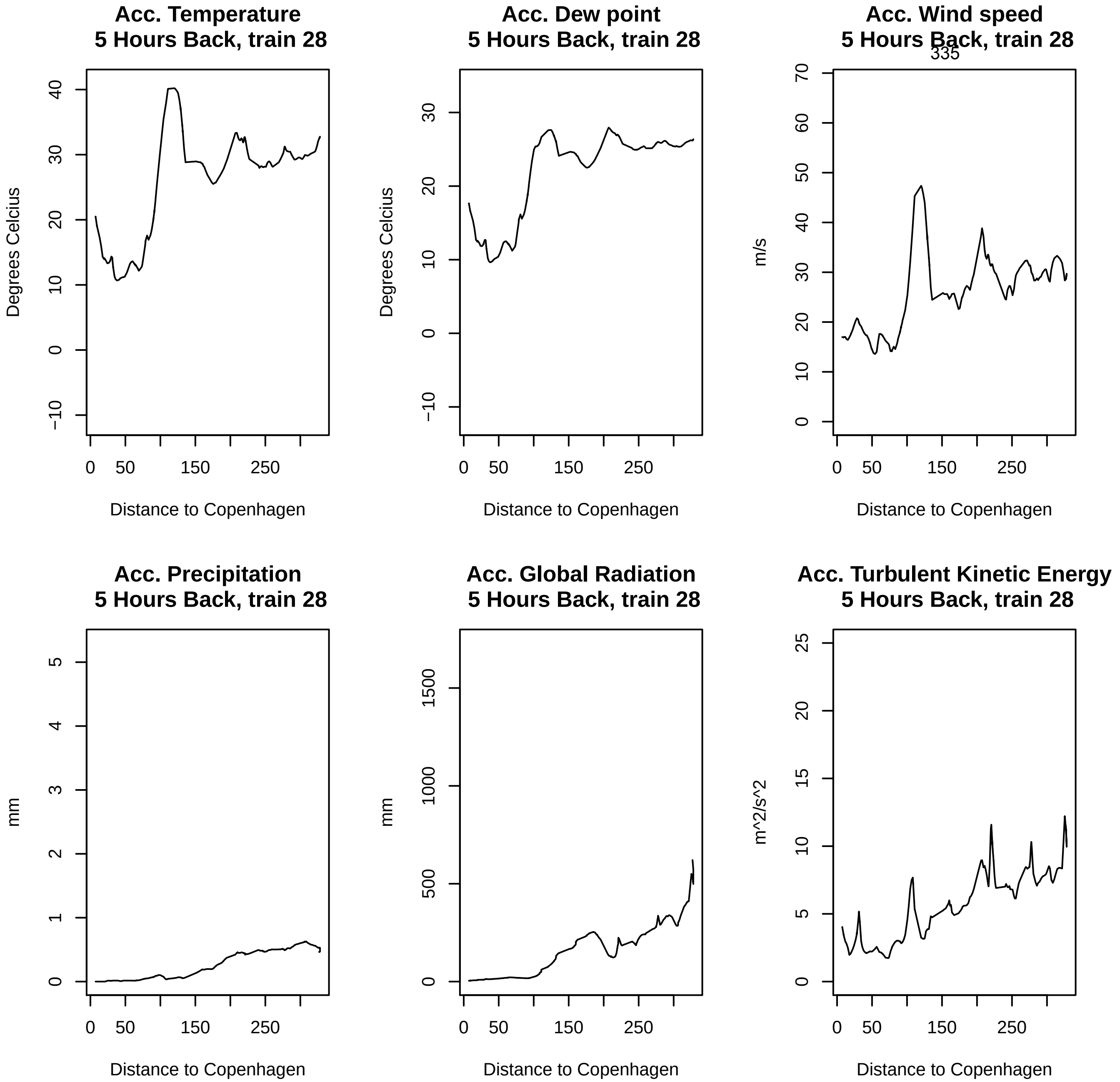
Acc. Temperature
24 Hours Back, train 27
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 27
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 27
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 27
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 27
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 27
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

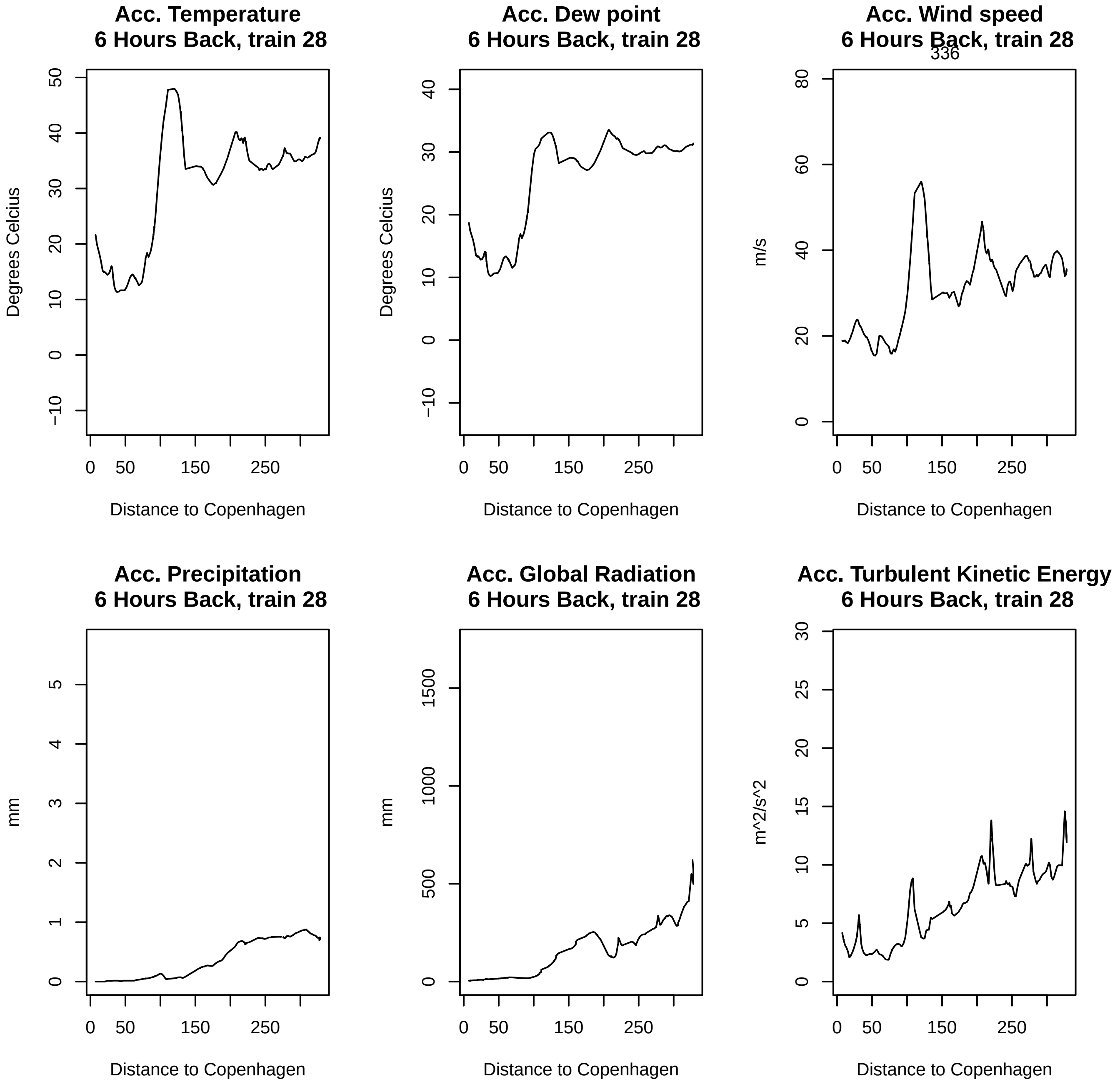

Temperature, train 28
Degrees Celcius
Distance to Copenhagen
Dew point, train 28
Degrees Celcius
Distance to Copenhagen
Wind speed, train 28
m/s
Distance to Copenhagen
Precipitation, train 28
mm
Distance to Copenhagen
Global Radiation, train 28
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 28
m^2/s^2
Distance to Copenhagen

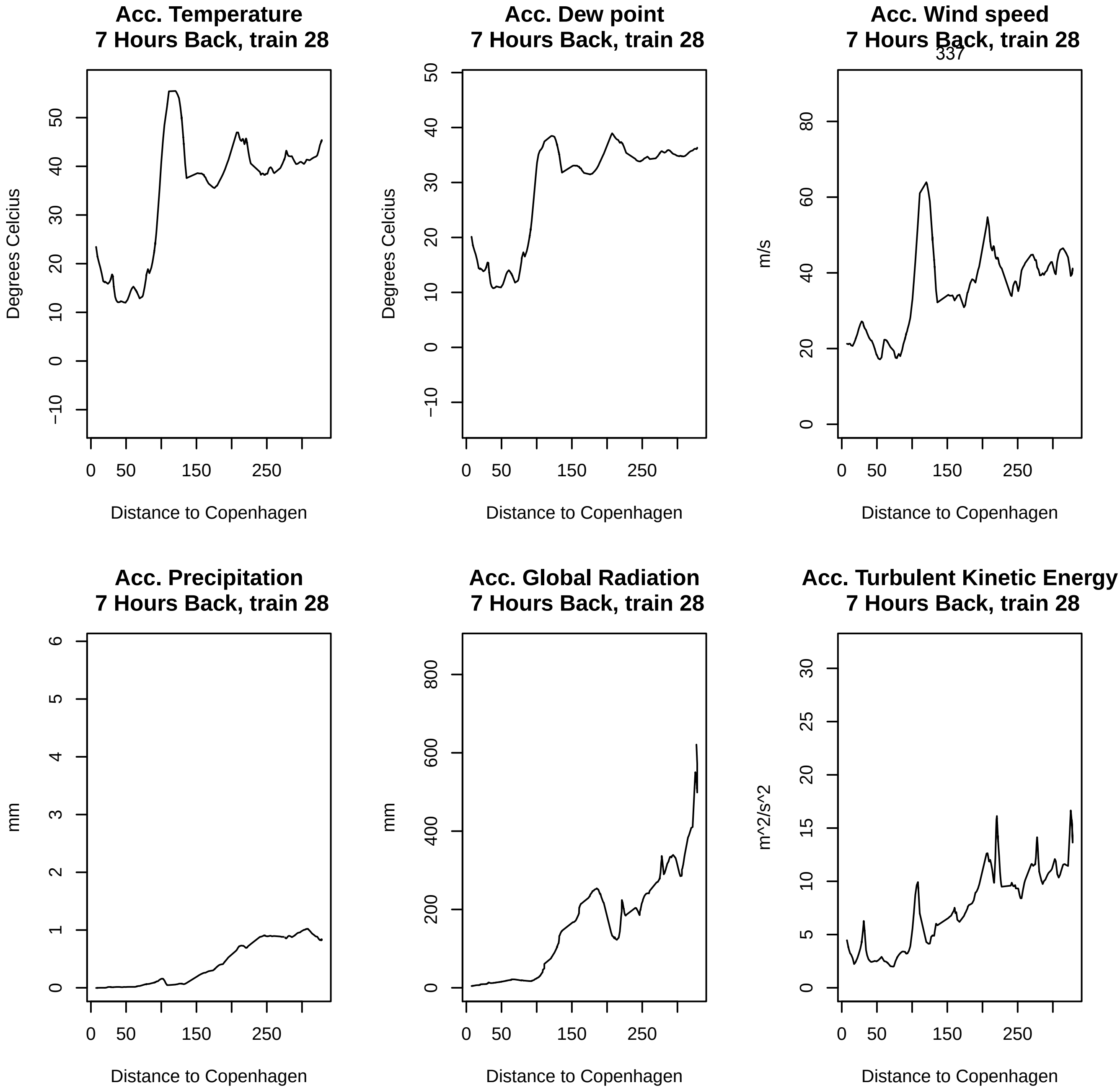


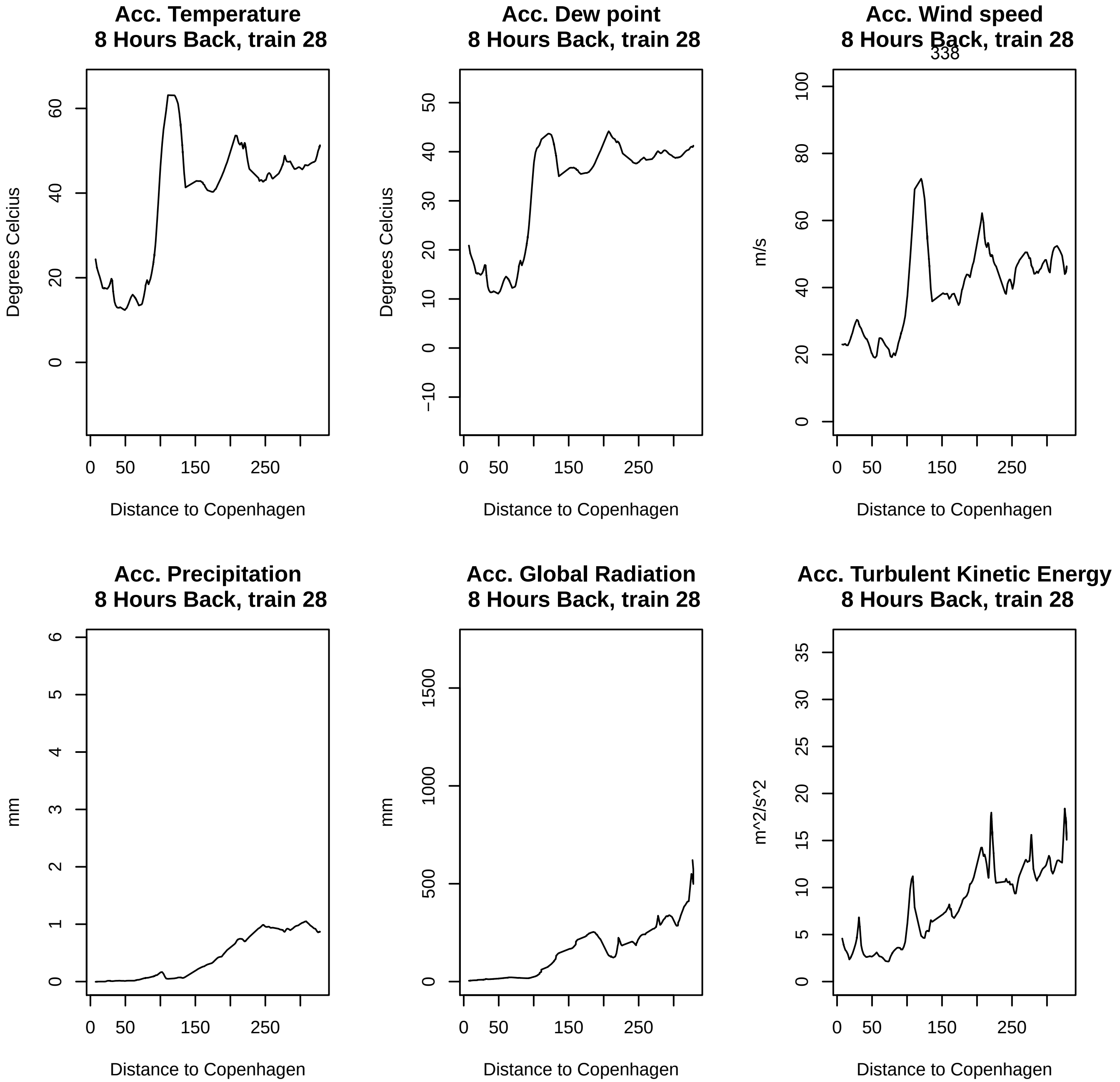
Acc. Temperature
3 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 28
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 28
m^2/s^2
Distance to Copenhagen

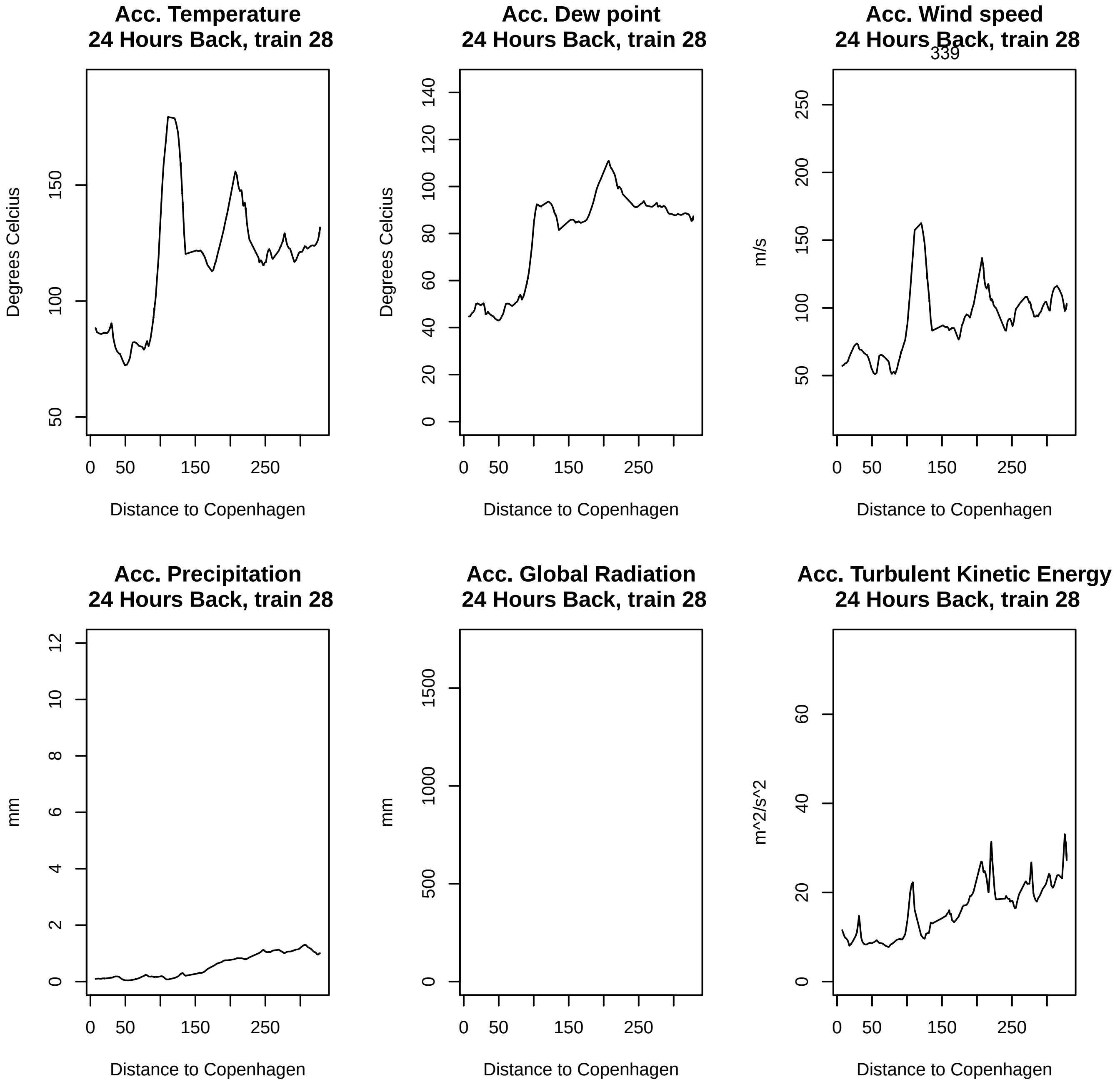

Acc. Temperature
4 Hours Back, train 28
Degrees Celcius
−10
0
10
20
30
Distance to Copenhagen
0
50
150
250
Acc. Dew point
4 Hours Back, train 28
Degrees Celcius
−10
0
10
20
Distance to Copenhagen
0
50
150
250
Acc. Wind speed
4 Hours Back, train 28
m/s
0
10
20
30
40
50
Distance to Copenhagen
0
50
150
250
Acc. Precipitation
4 Hours Back, train 28
mm
0
1
2
3
4
Distance to Copenhagen
0
50
150
250
Acc. Global Radiation
4 Hours Back, train 28
mm
0
500
1000
1500
Distance to Copenhagen
0
50
150
250
Acc. Turbulent Kinetic Energy
4 Hours Back, train 28
m^2/s^2
0
5
10
15
20
Distance to Copenhagen
0
50
150
250

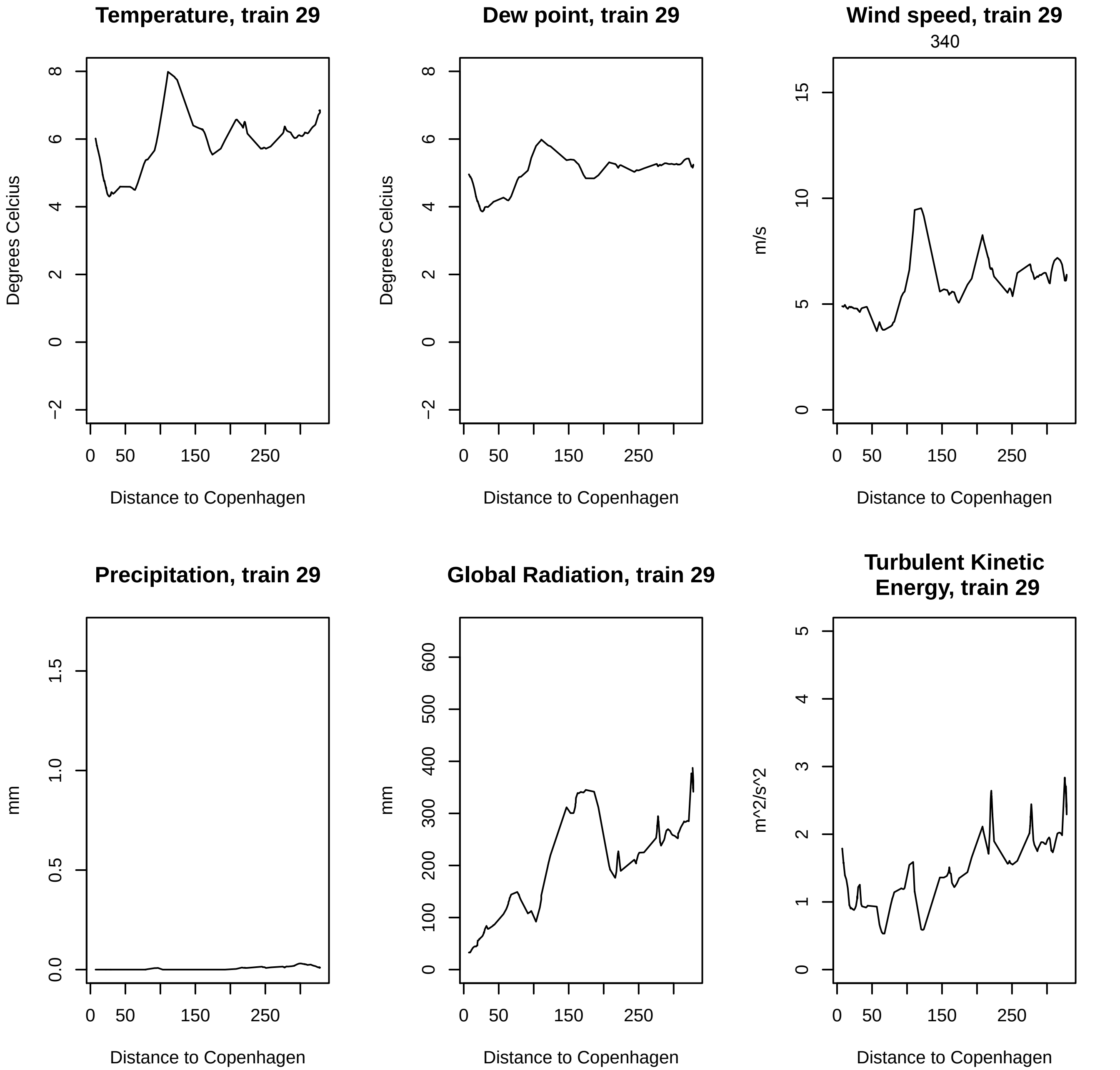

Acc. Temperature
5 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 28
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 28
m^2/s^2
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 28
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 28
m^2/s^2
Distance to Copenhagen

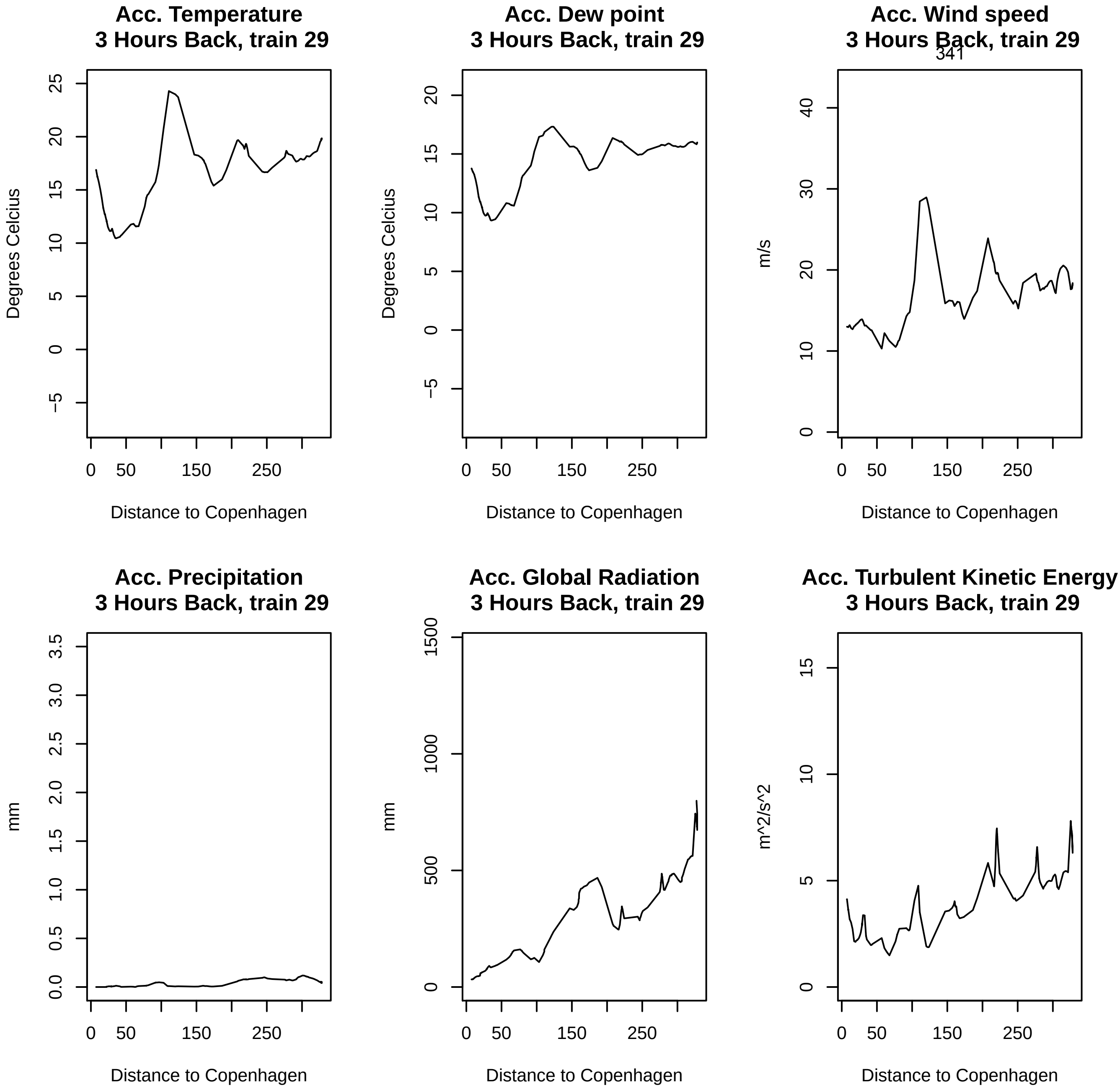

Acc. Temperature
7 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 28
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 28
m^2/s^2
Distance to Copenhagen


Acc. Temperature
8 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 28
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 28
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 28
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 28
m^2/s^2
Distance to Copenhagen

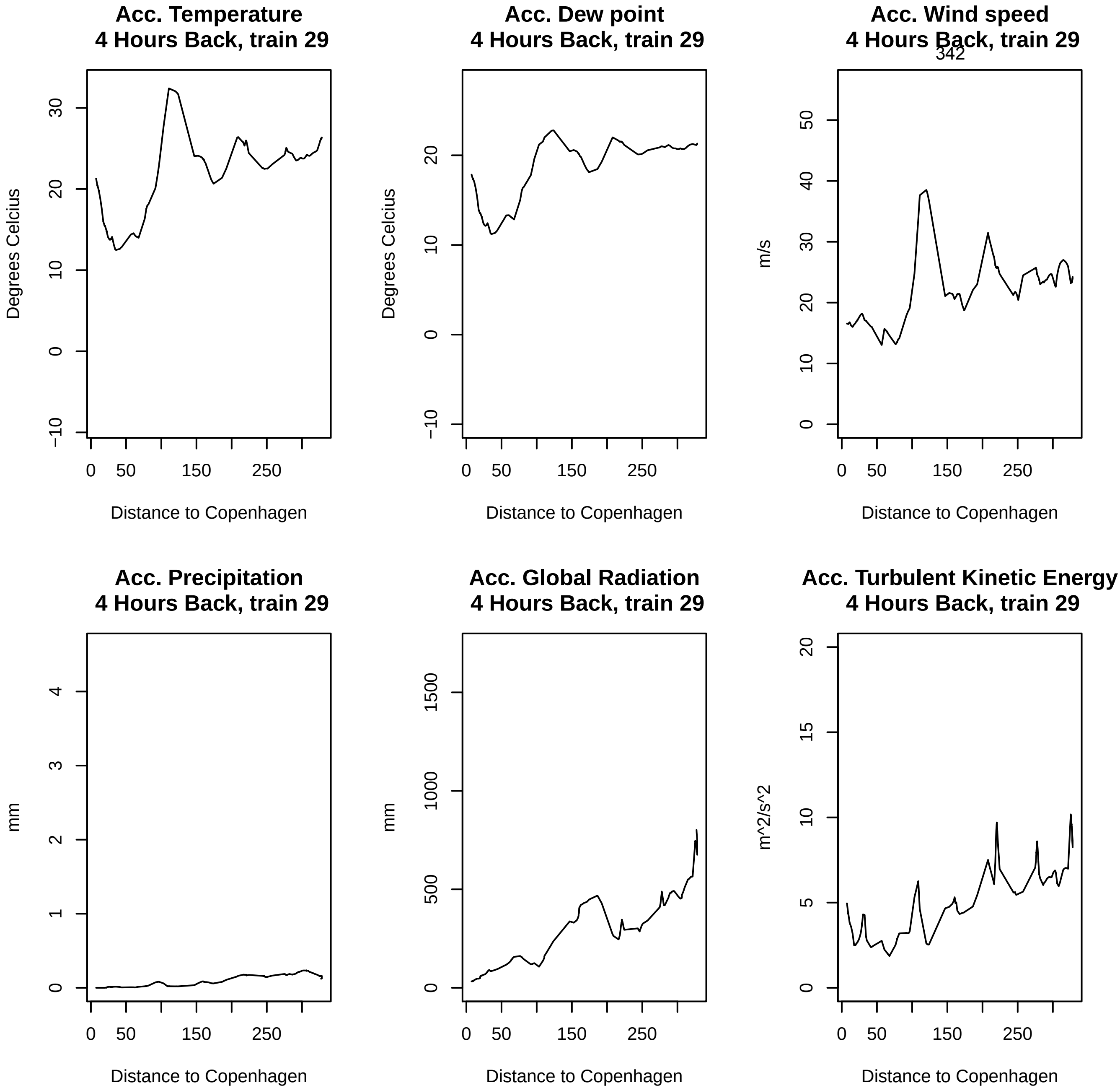

Acc. Temperature
24 Hours Back, train 28
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 28
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 28
339
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 28
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 28
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 28
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

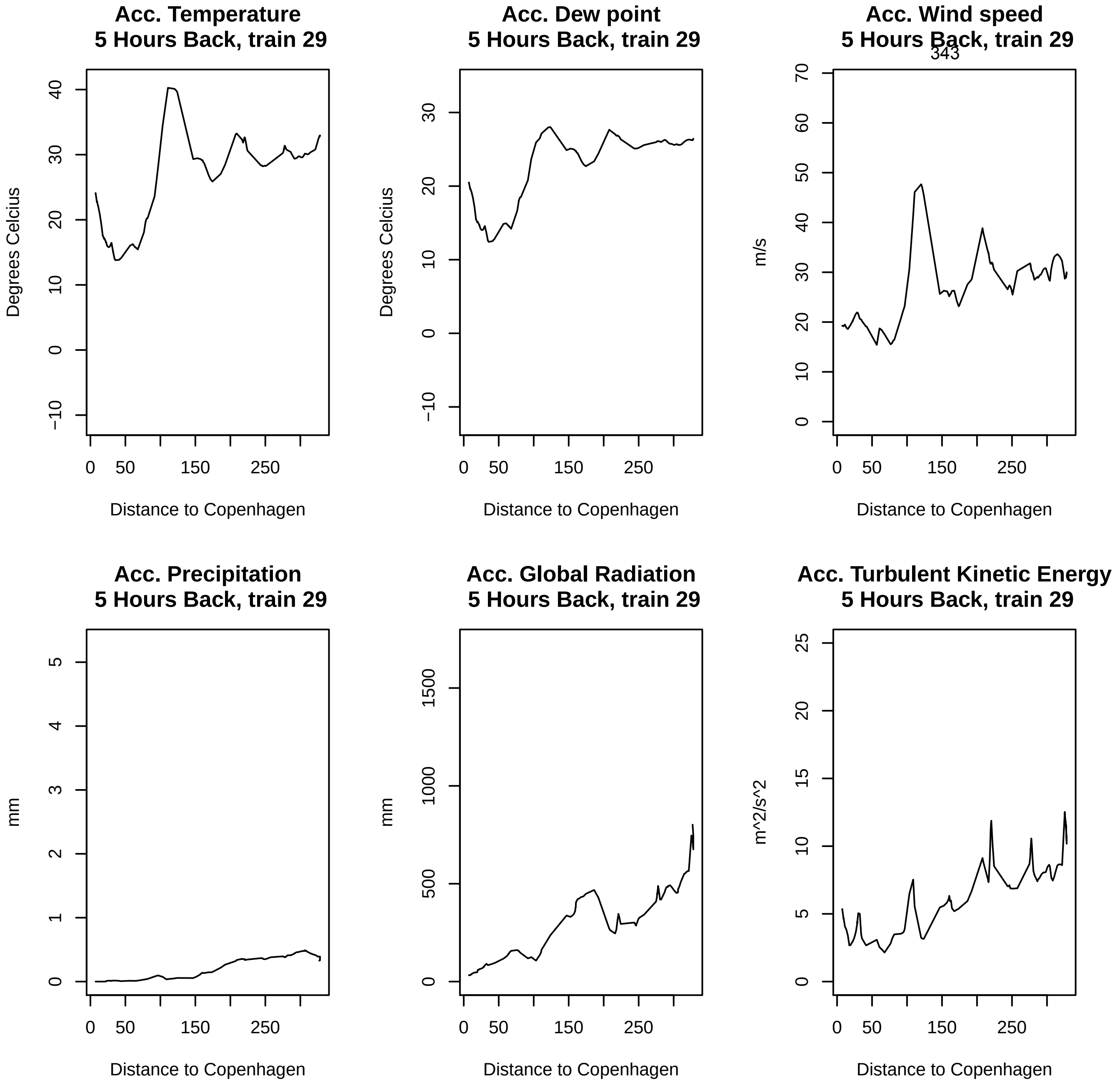


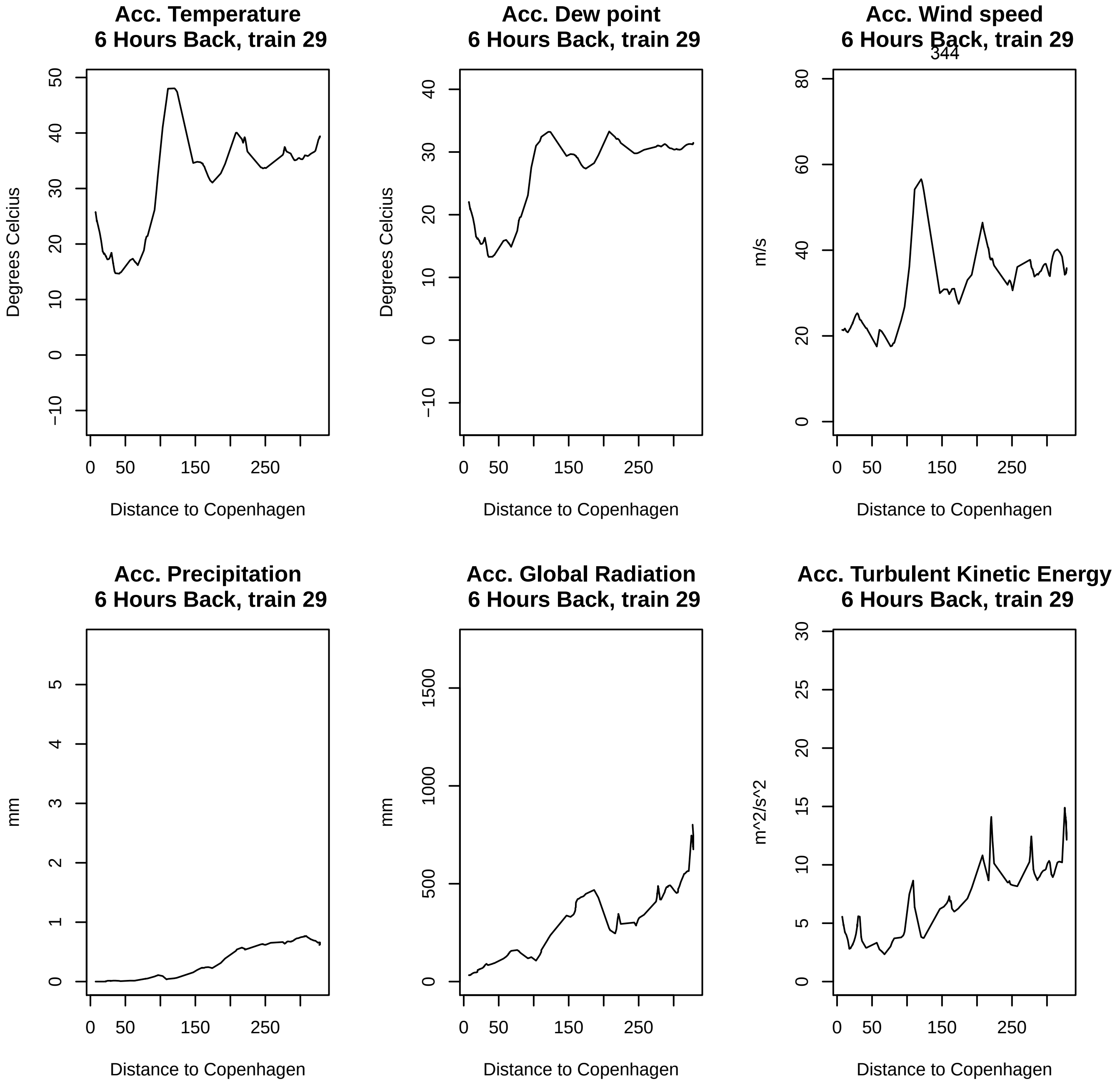
Temperature, train 29
Degrees Celcius
Distance to Copenhagen
Dew point, train 29
Degrees Celcius
Distance to Copenhagen
Wind speed, train 29
m/s
Distance to Copenhagen
Precipitation, train 29
mm
Distance to Copenhagen
Global Radiation, train 29
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 29
m^2/s^2
Distance to Copenhagen

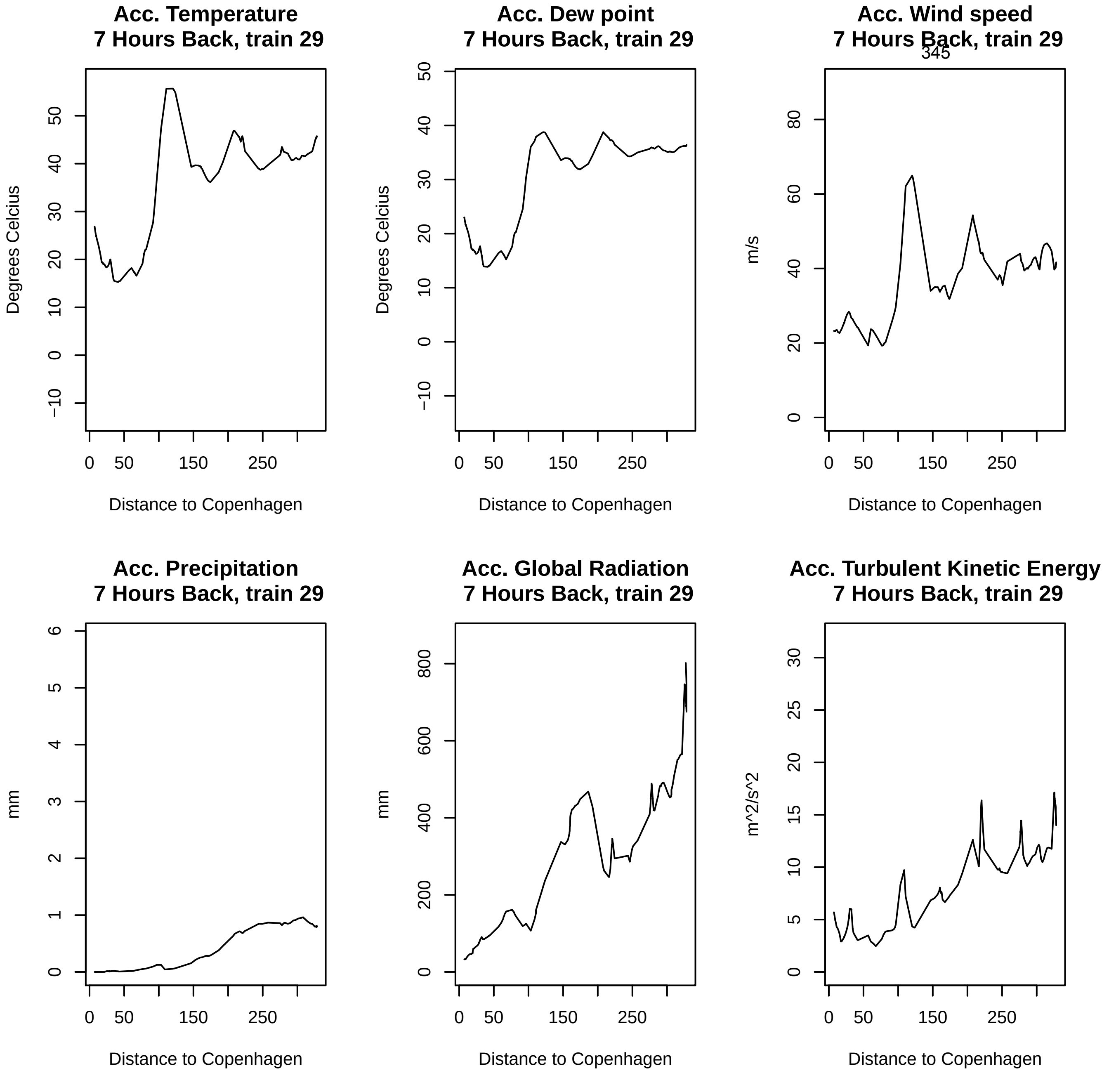


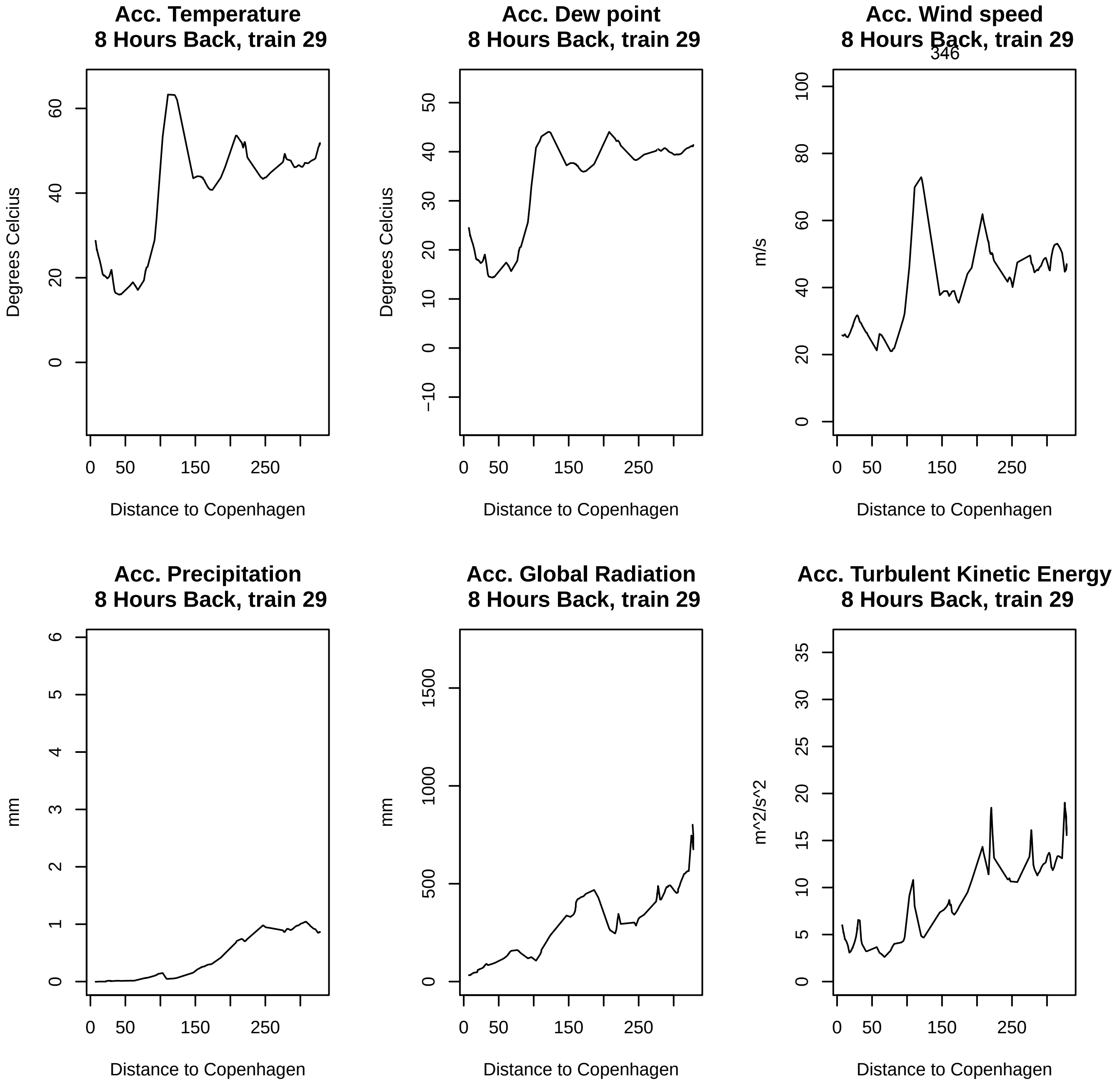
Acc. Temperature
3 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 29
m/s
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 29
m^2/s^2
Distance to Copenhagen


Acc. Temperature
4 Hours Back, train 29
Degrees Celcius
−10
0
10
20
30
0
50
150
250
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 29
Degrees Celcius
−10
0
10
20
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 29
m/s
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 29
mm
0
1
2
3
4
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 29
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 29
m^2/s^2
0
5
10
15
20
0
50
150
250
Distance to Copenhagen

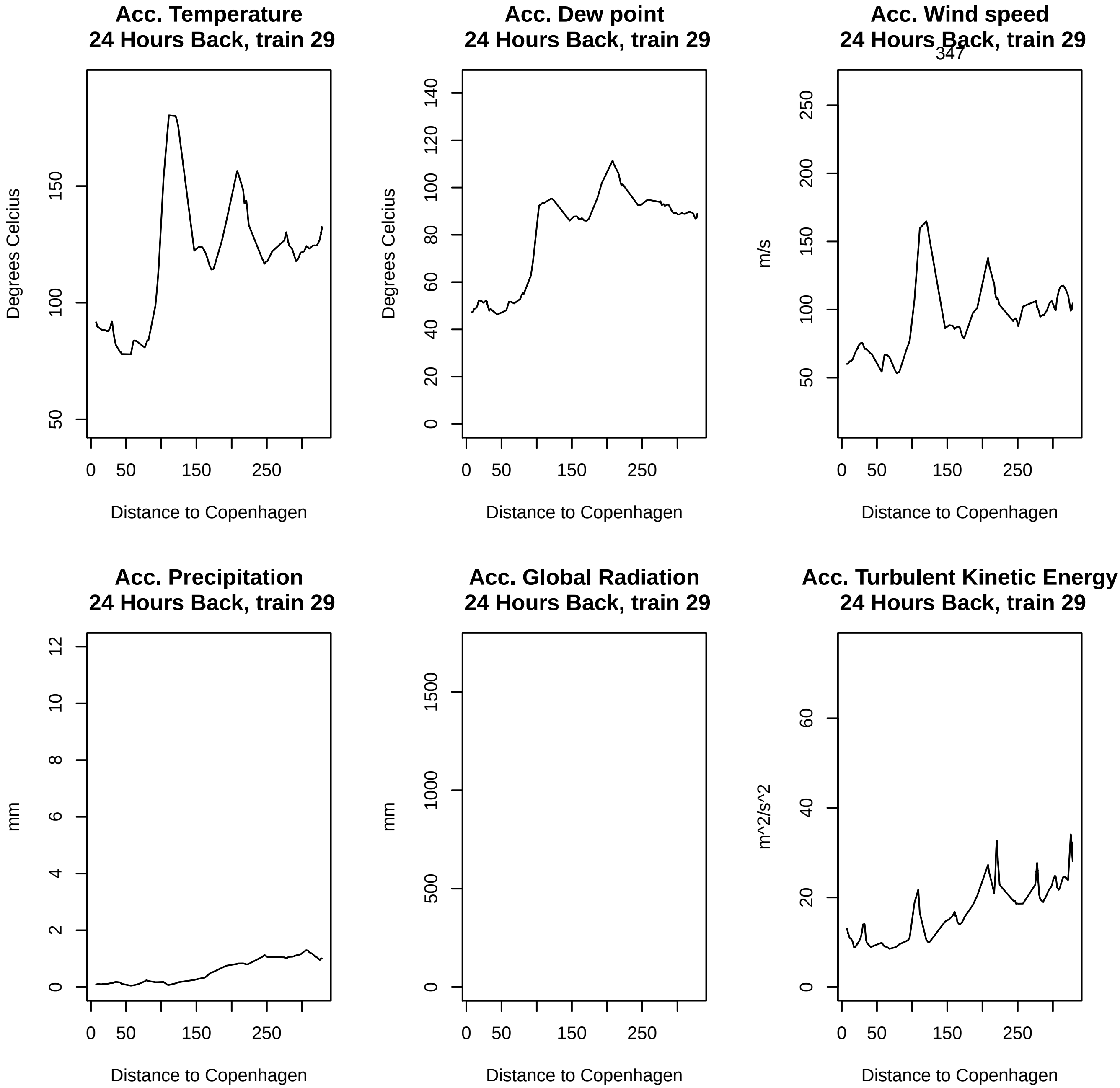

Acc. Temperature
5 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 29
m/s
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 29
m^2/s^2
Distance to Copenhagen

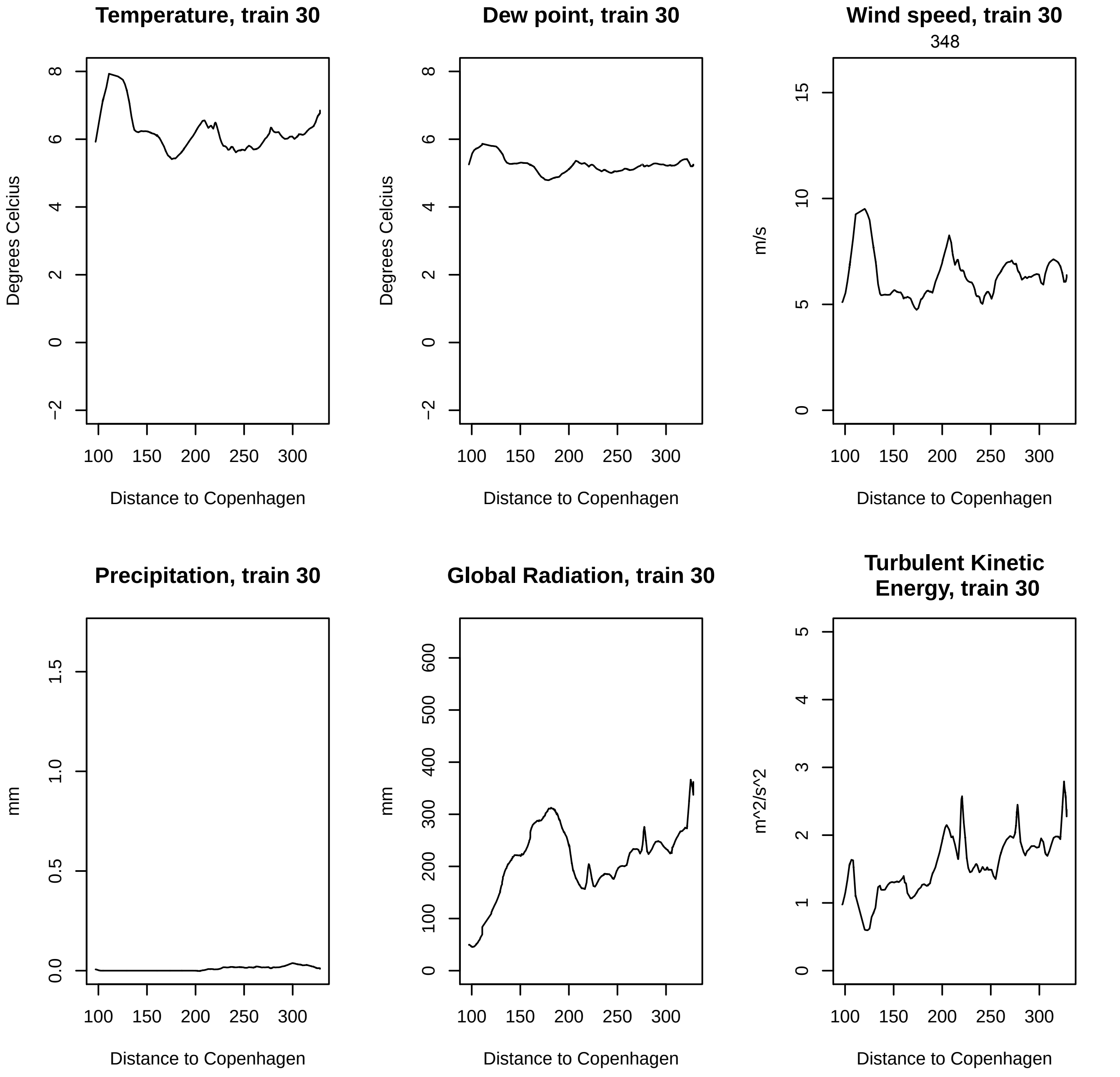

Acc. Temperature
6 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 29
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 29
m^2/s^2
Distance to Copenhagen

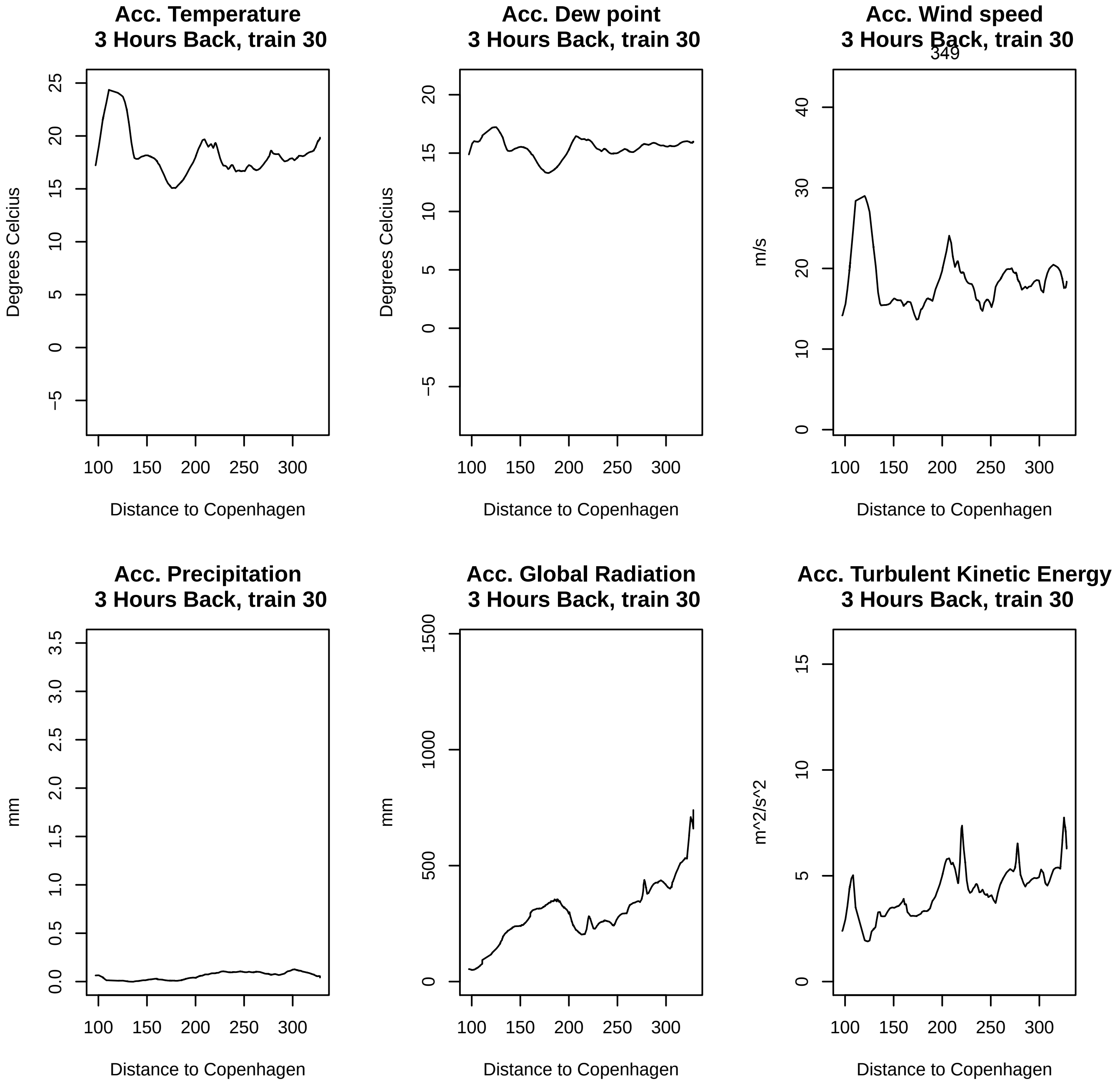

Acc. Temperature
7 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 29
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 29
m/s
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 29
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 29
m^2/s^2
Distance to Copenhagen

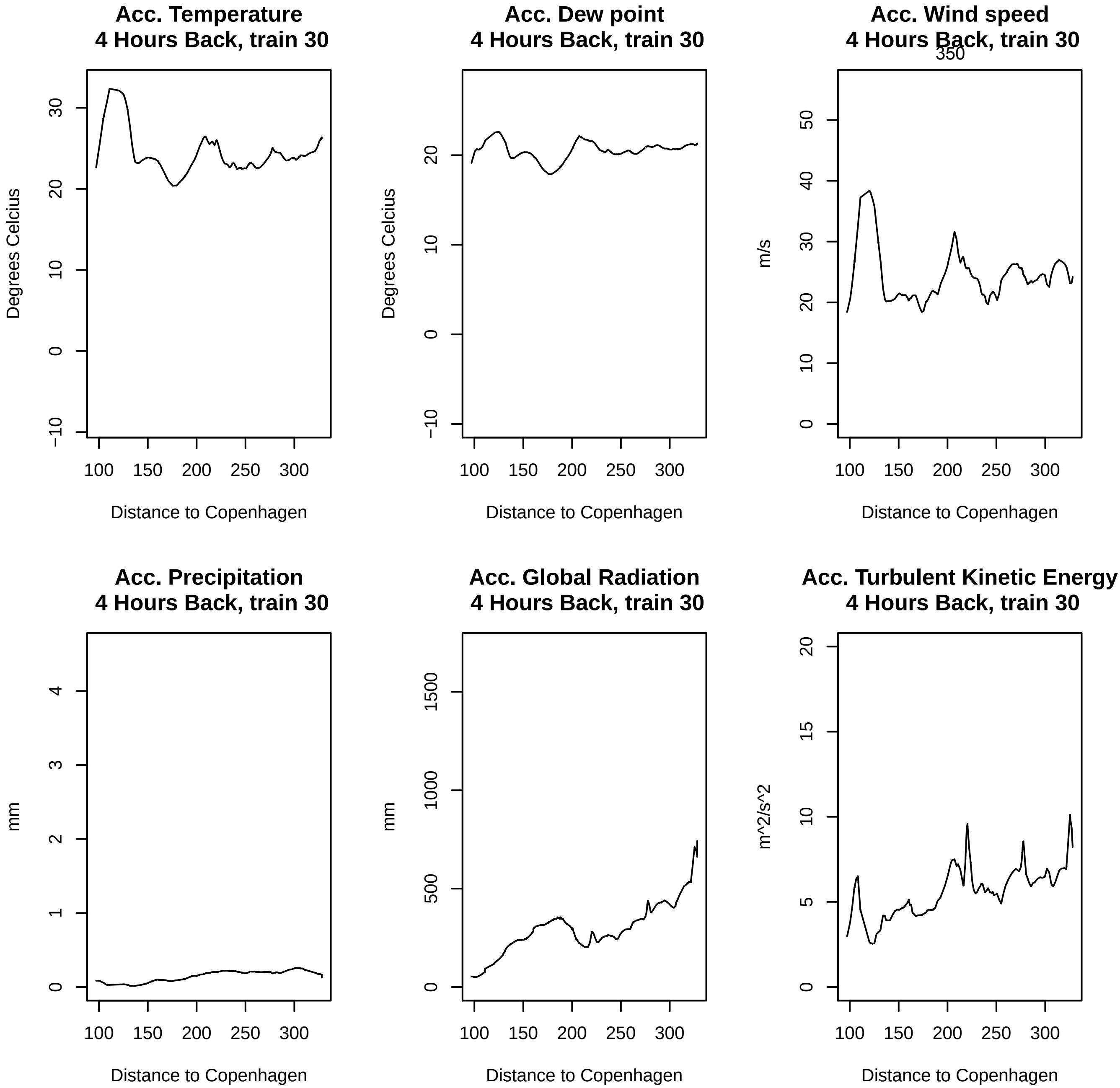


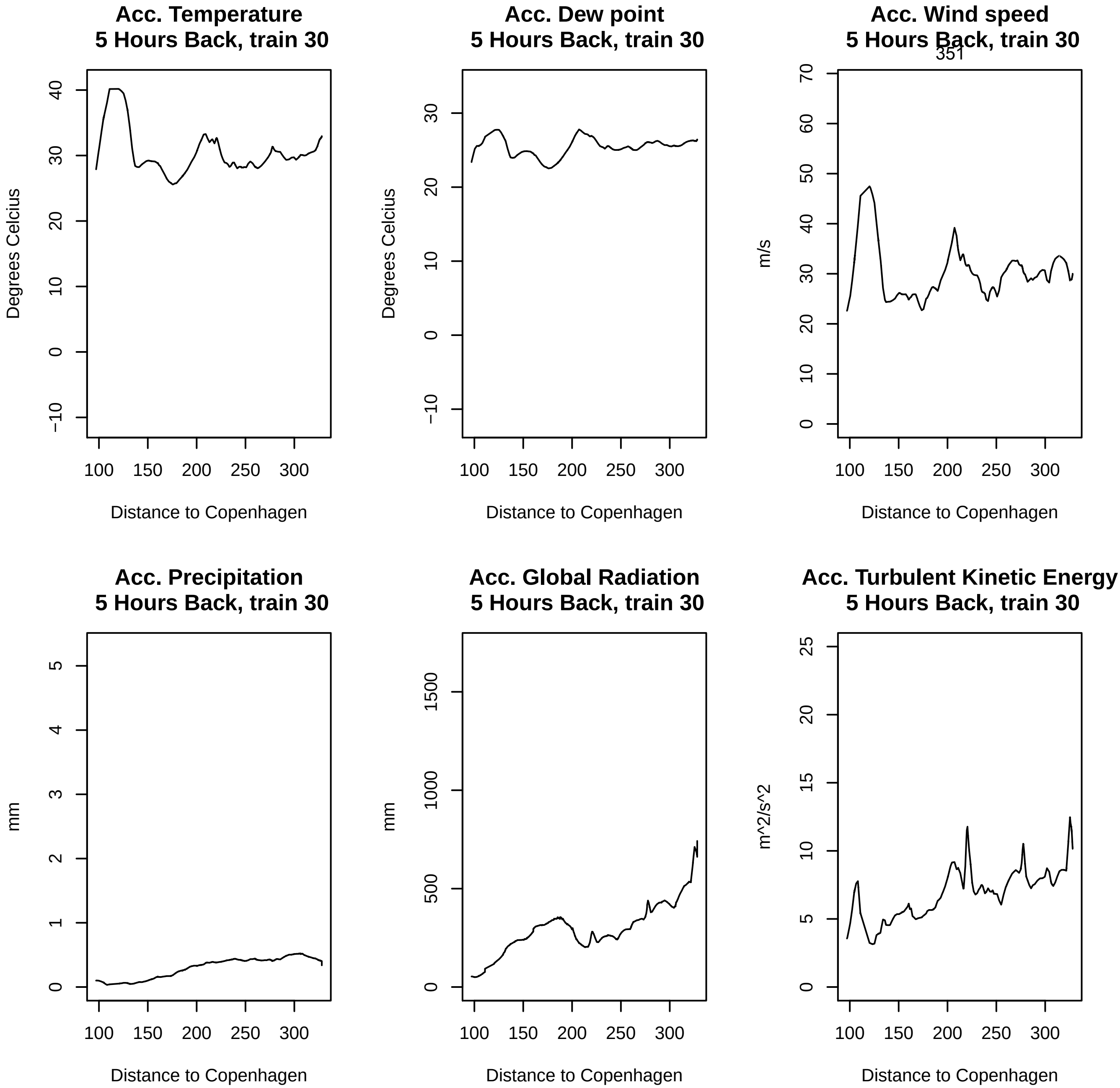
Acc. Temperature
8 Hours Back, train 29
Degrees Celcius
0
20
40
60
0
50
150
250
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 29
Degrees Celcius
−10
0
10
20
30
40
50
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 29
m/s
0
20
40
60
80
100
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 29
mm
0
1
2
3
4
5
6
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 29
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 29
m^2/s^2
0
5
10
15
20
25
30
35
0
50
150
250
Distance to Copenhagen

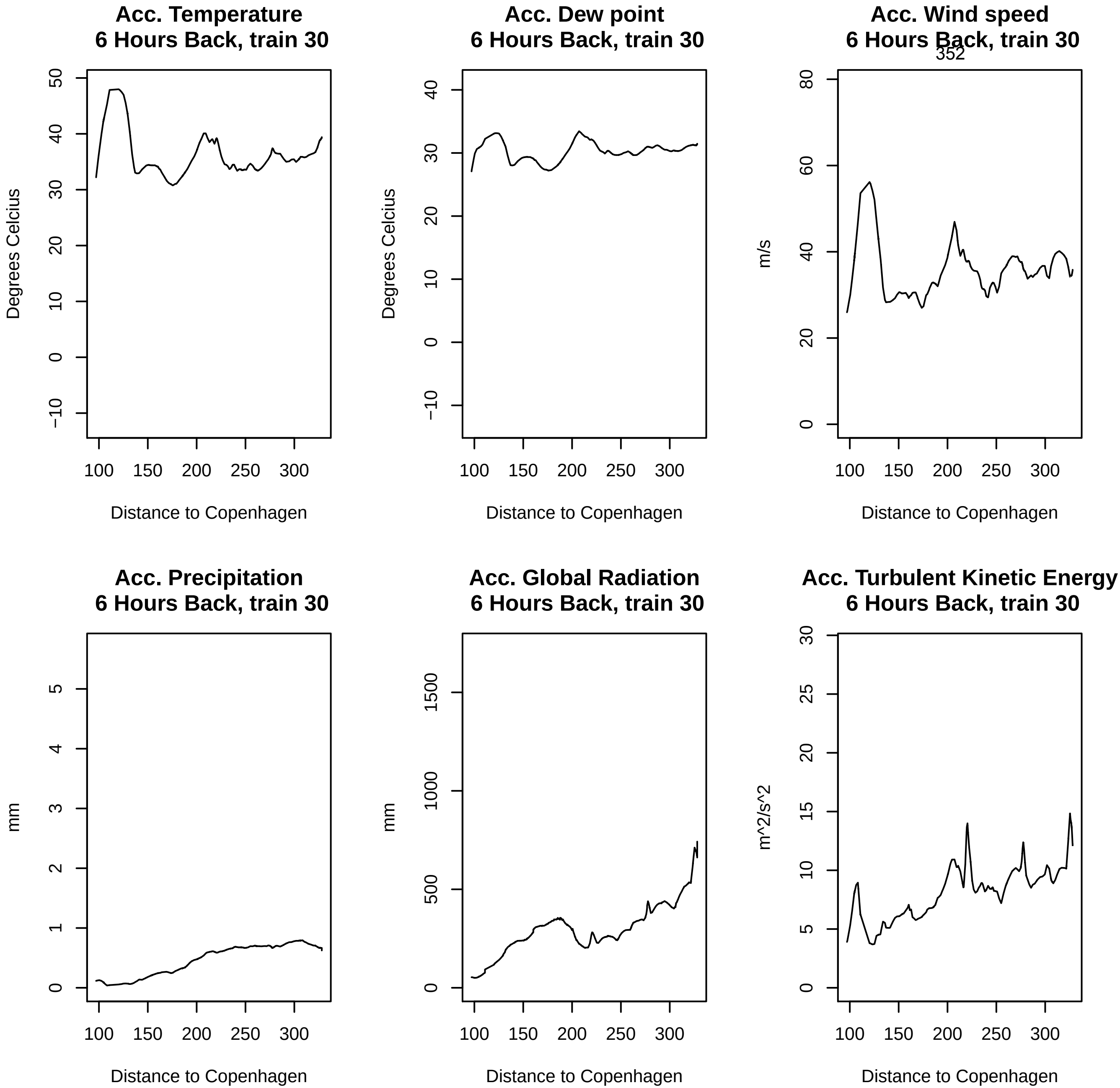

Acc. Temperature
24 Hours Back, train 29
Degrees Celcius
50
100
150
0
50
150
250
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 29
Degrees Celcius
0
20
40
60
80
100
120
140
0
50
150
250
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 29
m/s
50
100
150
200
250
0
50
150
250
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 29
mm
0
2
4
6
8
10
12
0
50
150
250
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 29
mm
0
500
1000
1500
0
50
150
250
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 29
m^2/s^2
0
20
40
60
0
50
150
250
Distance to Copenhagen

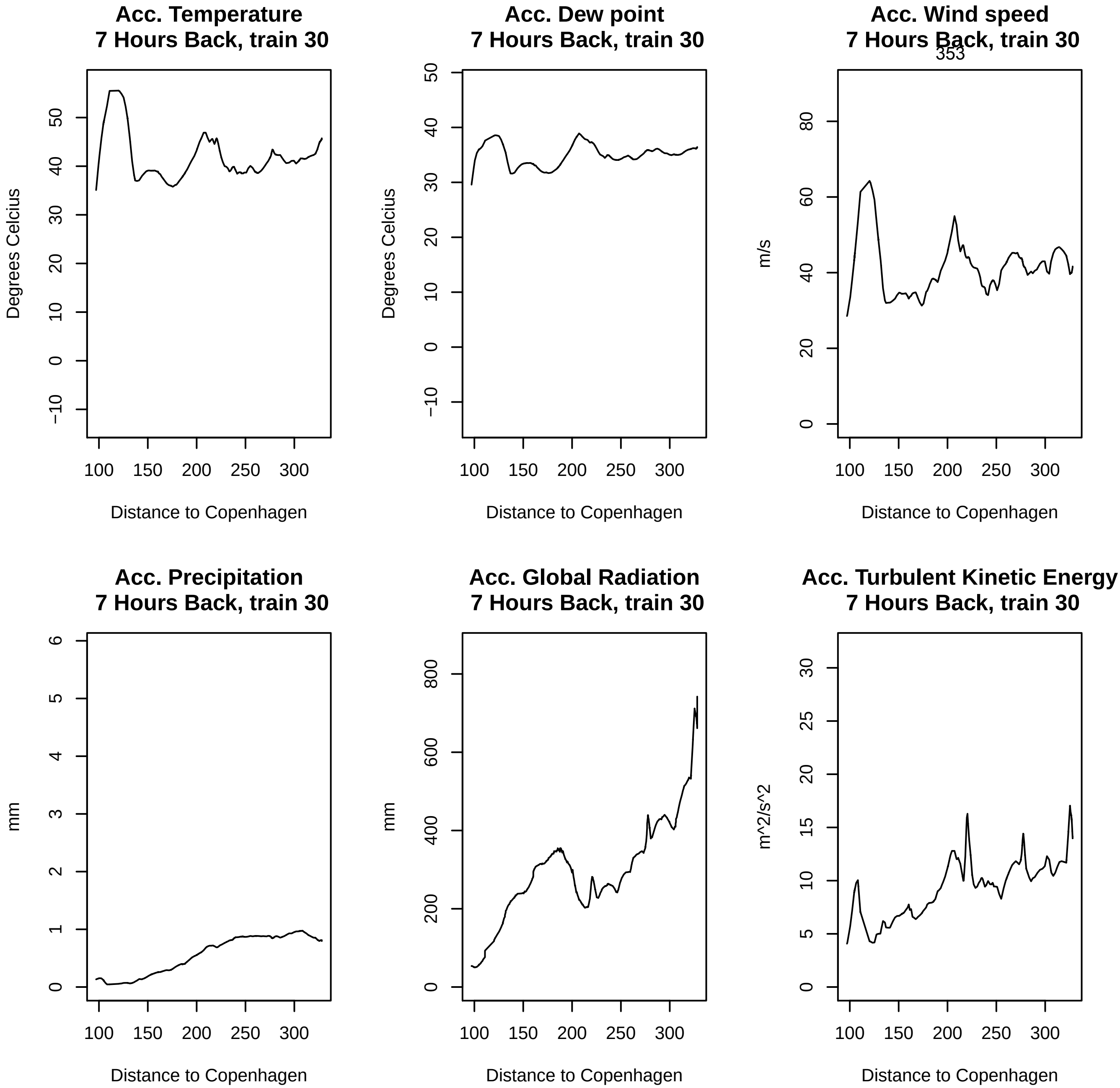

Temperature, train 30
Degrees Celcius
Distance to Copenhagen
Dew point, train 30
Degrees Celcius
Distance to Copenhagen
Wind speed, train 30
m/s
Distance to Copenhagen
Precipitation, train 30
mm
Distance to Copenhagen
Global Radiation, train 30
mm
Distance to Copenhagen
Turbulent Kinetic Energy, train 30
m^2/s^2
Distance to Copenhagen

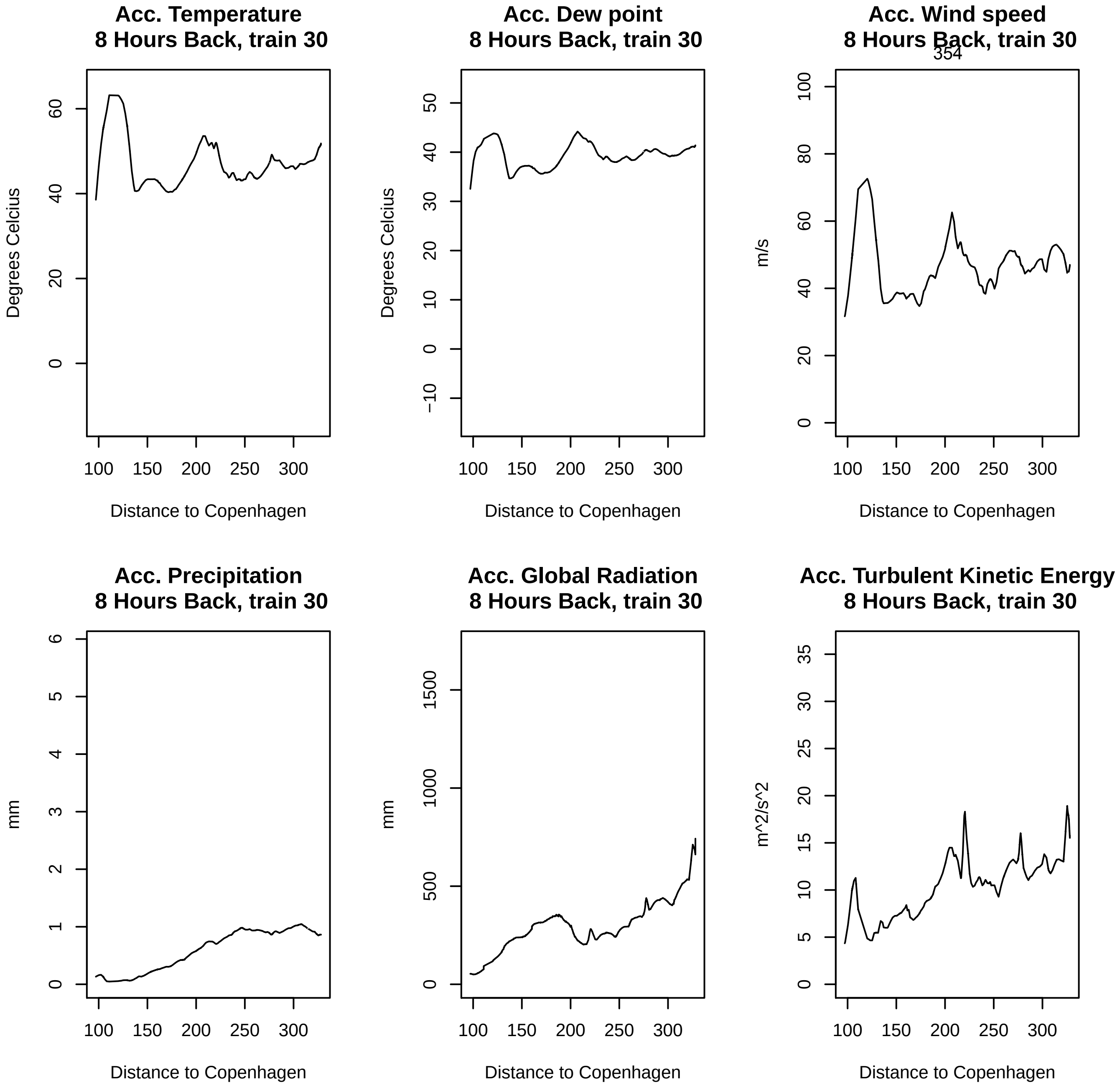

Acc. Temperature
3 Hours Back, train 30
Degrees Celcius
−5
0
5
10
15
20
25
100
150
200
250
300
Distance to Copenhagen
Acc. Dew point
3 Hours Back, train 30
Degrees Celcius
−5
0
5
10
15
20
100
150
200
250
300
Distance to Copenhagen
Acc. Wind speed
3 Hours Back, train 30
m/s
0
10
20
30
40
100
150
200
250
300
Distance to Copenhagen
Acc. Precipitation
3 Hours Back, train 30
mm
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
100
150
200
250
300
Distance to Copenhagen
Acc. Global Radiation
3 Hours Back, train 30
mm
0
500
1000
1500
100
150
200
250
300
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
3 Hours Back, train 30
m^2/s^2
0
5
10
15
100
150
200
250
300
Distance to Copenhagen

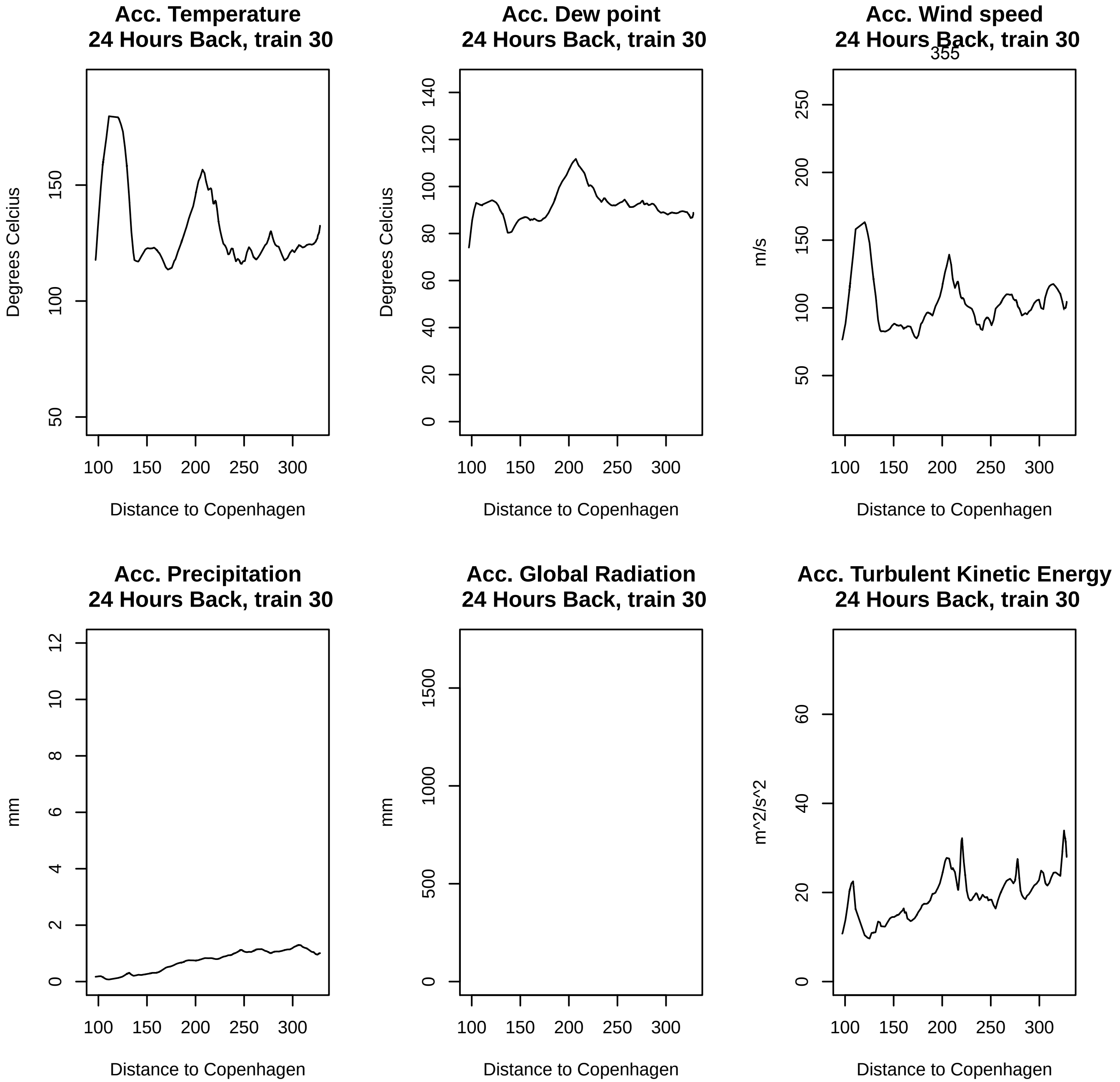

Acc. Temperature
4 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
4 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
4 Hours Back, train 30
350
m/s
Distance to Copenhagen
Acc. Precipitation
4 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Global Radiation
4 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
4 Hours Back, train 30
m^2/s^2
Distance to Copenhagen
100
150
200
250
300


Acc. Temperature
5 Hours Back, train 30
Degrees Celcius
−10
0
10
20
30
40
100
150
200
250
300
Distance to Copenhagen
Acc. Dew point
5 Hours Back, train 30
Degrees Celcius
−10
0
10
20
30
100
150
200
250
300
Distance to Copenhagen
Acc. Wind speed
5 Hours Back, train 30
m/s
0
10
20
30
40
50
60
70
100
150
200
250
300
Distance to Copenhagen
Acc. Precipitation
5 Hours Back, train 30
mm
0
1
2
3
4
5
100
150
200
250
300
Distance to Copenhagen
Acc. Global Radiation
5 Hours Back, train 30
mm
0
500
1000
1500
100
150
200
250
300
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
5 Hours Back, train 30
m^2/s^2
0
5
10
15
20
25
100
150
200
250
300
Distance to Copenhagen


Acc. Temperature
6 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
6 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
6 Hours Back, train 30
m/s
Distance to Copenhagen
Acc. Precipitation
6 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Global Radiation
6 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
6 Hours Back, train 30
m^2/s^2
Distance to Copenhagen

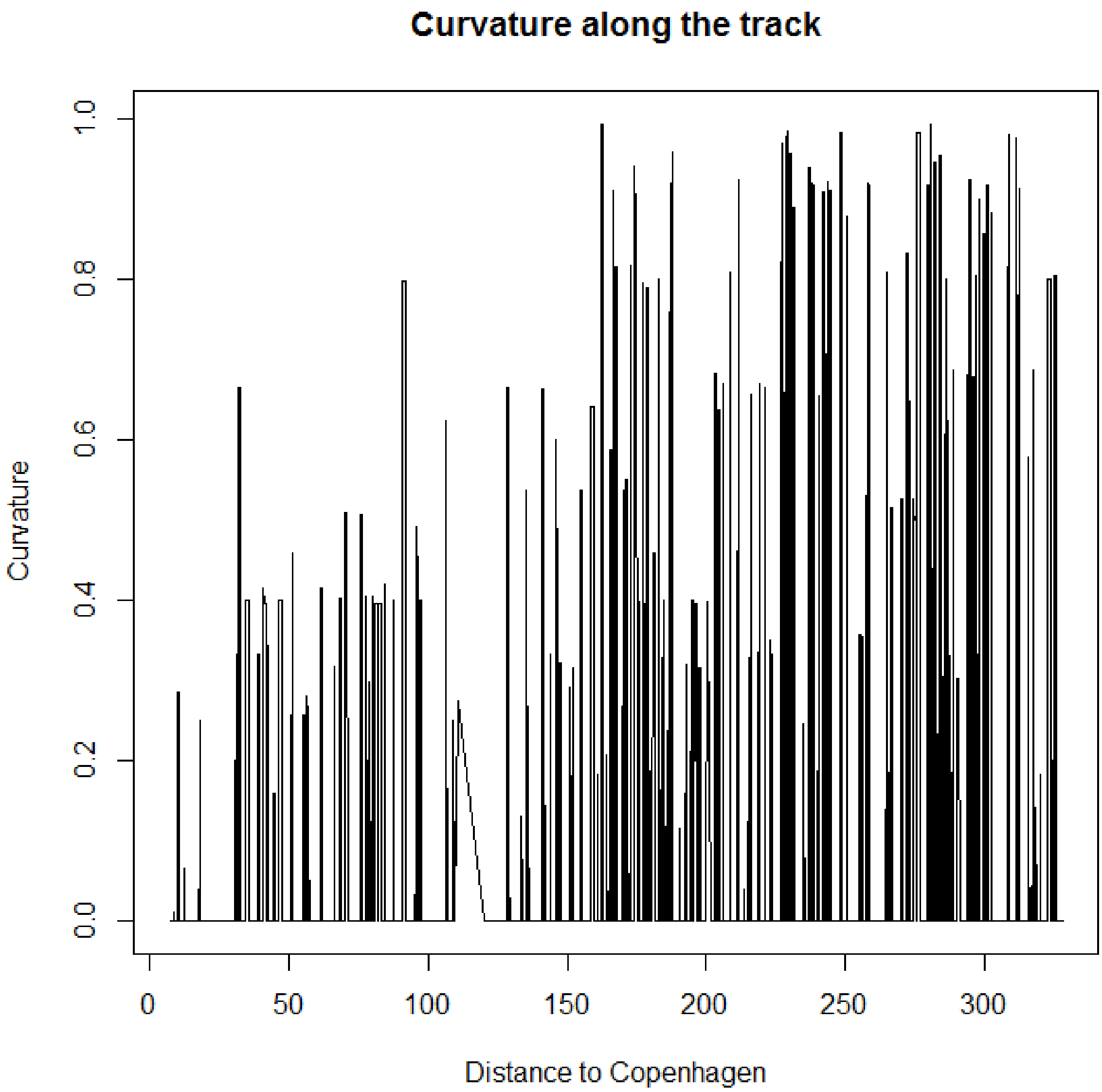

Acc. Temperature
7 Hours Back, train 30
Degrees Celcius
−10
0
10
20
30
40
50
100
150
200
250
300
Distance to Copenhagen
Acc. Dew point
7 Hours Back, train 30
Degrees Celcius
−10
0
10
20
30
40
50
100
150
200
250
300
Distance to Copenhagen
Acc. Wind speed
7 Hours Back, train 30
m/s
0
20
40
60
80
100
150
200
250
300
Distance to Copenhagen
Acc. Precipitation
7 Hours Back, train 30
mm
0
1
2
3
4
5
6
100
150
200
250
300
Distance to Copenhagen
Acc. Global Radiation
7 Hours Back, train 30
mm
0
200
400
600
800
100
150
200
250
300
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
7 Hours Back, train 30
m^2/s^2
0
5
10
15
20
25
30
100
150
200
250
300
Distance to Copenhagen

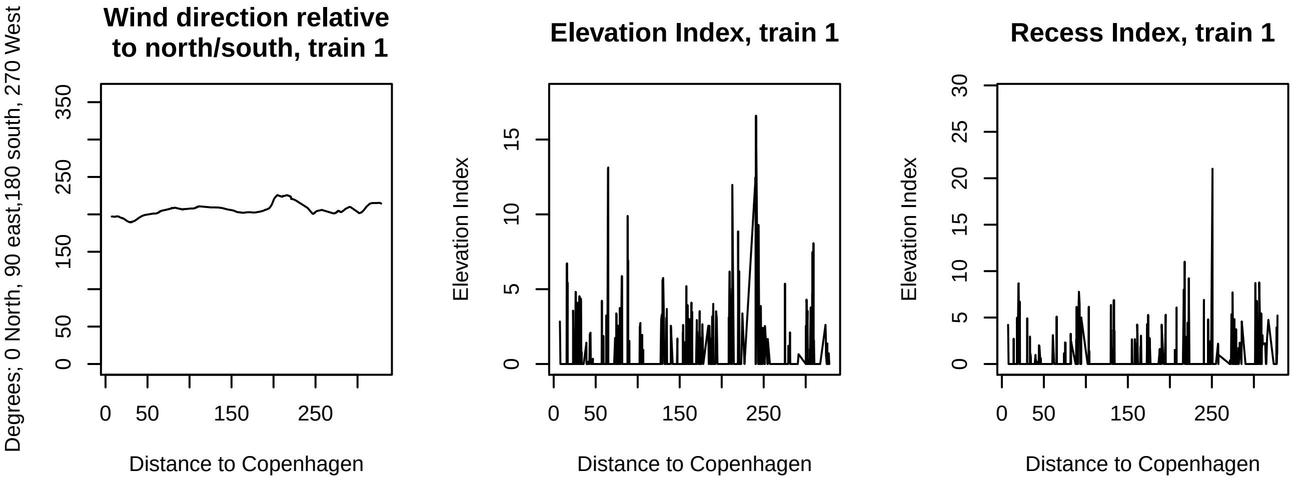

Acc. Temperature
8 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Dew point
8 Hours Back, train 30
Degrees Celcius
Distance to Copenhagen
Acc. Wind speed
8 Hours Back, train 30
m/s
Distance to Copenhagen
Acc. Precipitation
8 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Global Radiation
8 Hours Back, train 30
mm
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
8 Hours Back, train 30
m^2/s^2
Distance to Copenhagen

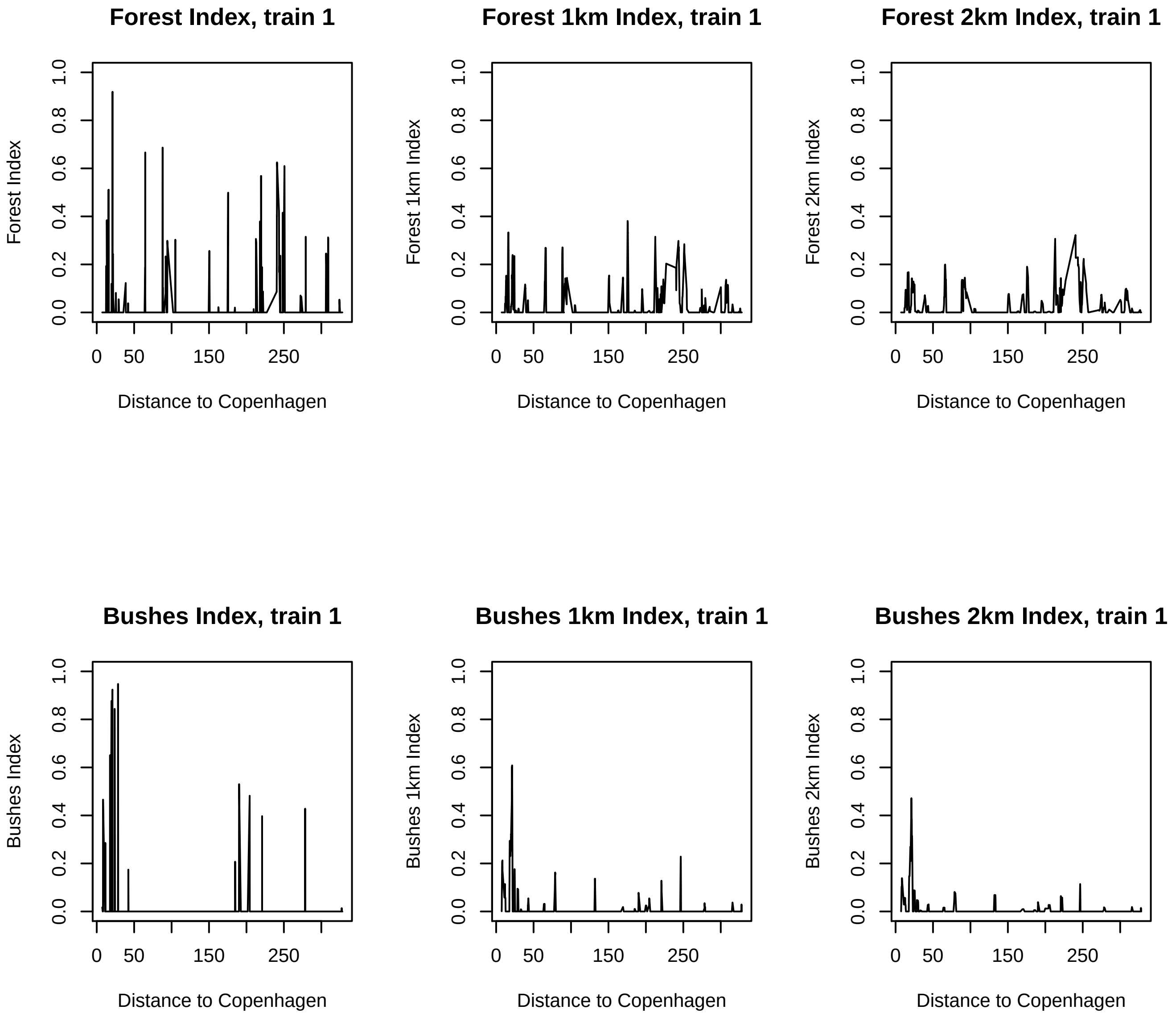


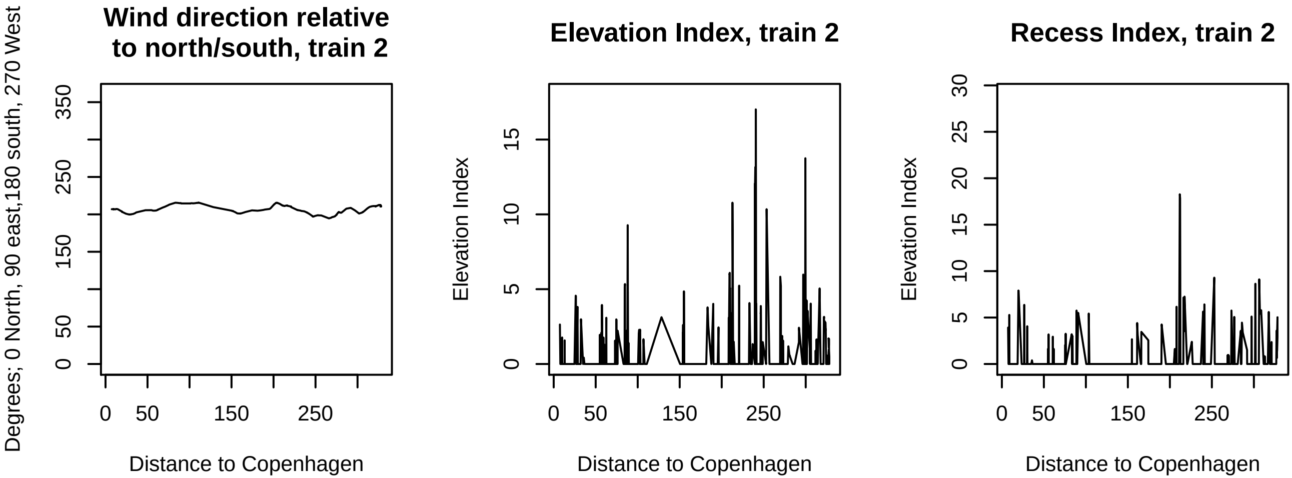
Acc. Temperature
24 Hours Back, train 30
Degrees Celcius
50
100
150
100
150
200
250
300
Distance to Copenhagen
Acc. Dew point
24 Hours Back, train 30
Degrees Celcius
0
20
40
60
80
100
120
140
100
150
200
250
300
Distance to Copenhagen
Acc. Wind speed
24 Hours Back, train 30
m/s
50
100
150
200
250
100
150
200
250
300
Distance to Copenhagen
Acc. Precipitation
24 Hours Back, train 30
mm
0
2
4
6
8
10
12
100
150
200
250
300
Distance to Copenhagen
Acc. Global Radiation
24 Hours Back, train 30
mm
0
500
1000
1500
100
150
200
250
300
Distance to Copenhagen
Acc. Turbulent Kinetic Energy
24 Hours Back, train 30
m^2/s^2
0
20
40
60
100
150
200
250
300
Distance to Copenhagen

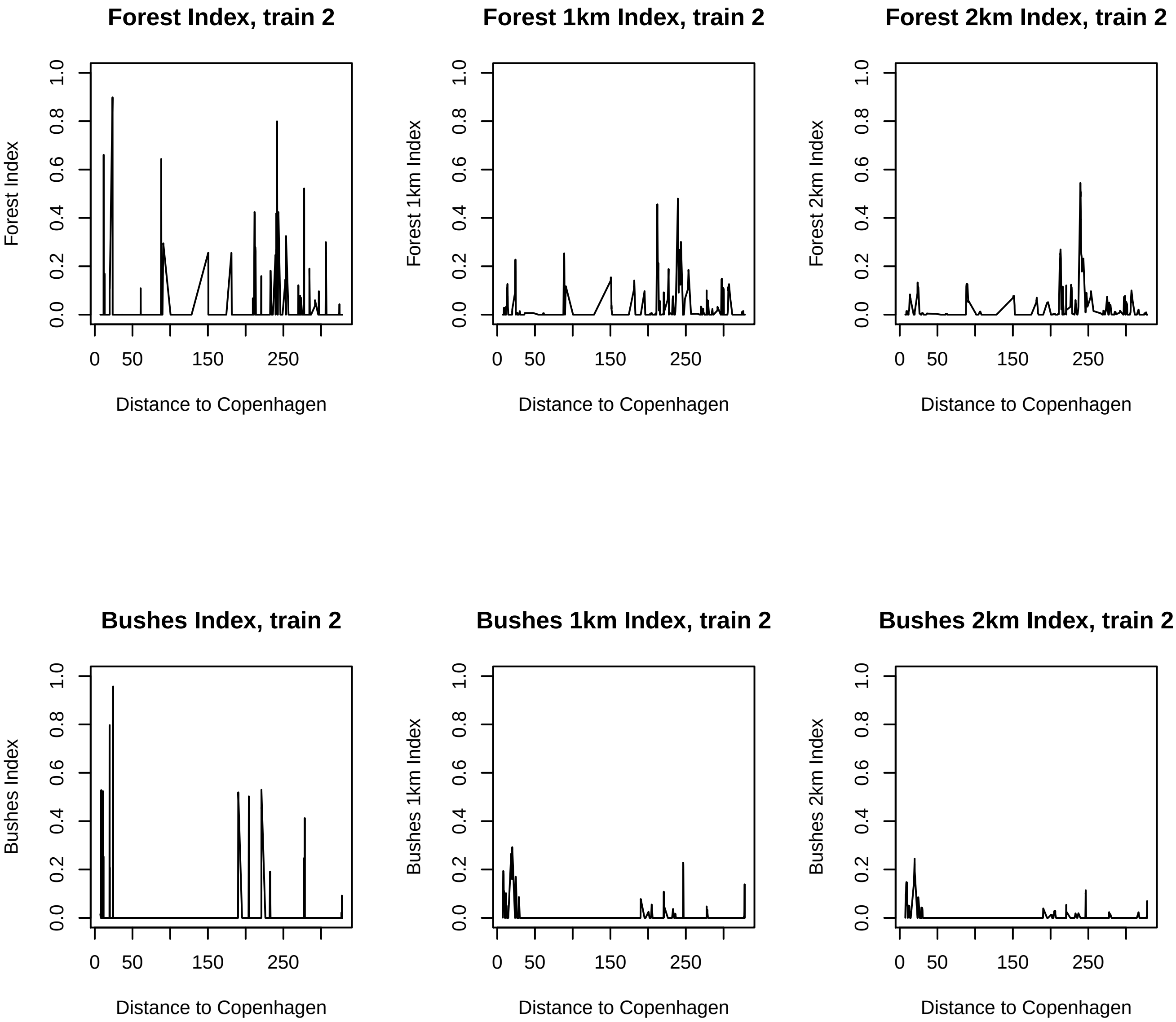
Annex H: Curvature of the track, and statistically significant indexes related to wind direction, along the train routes.

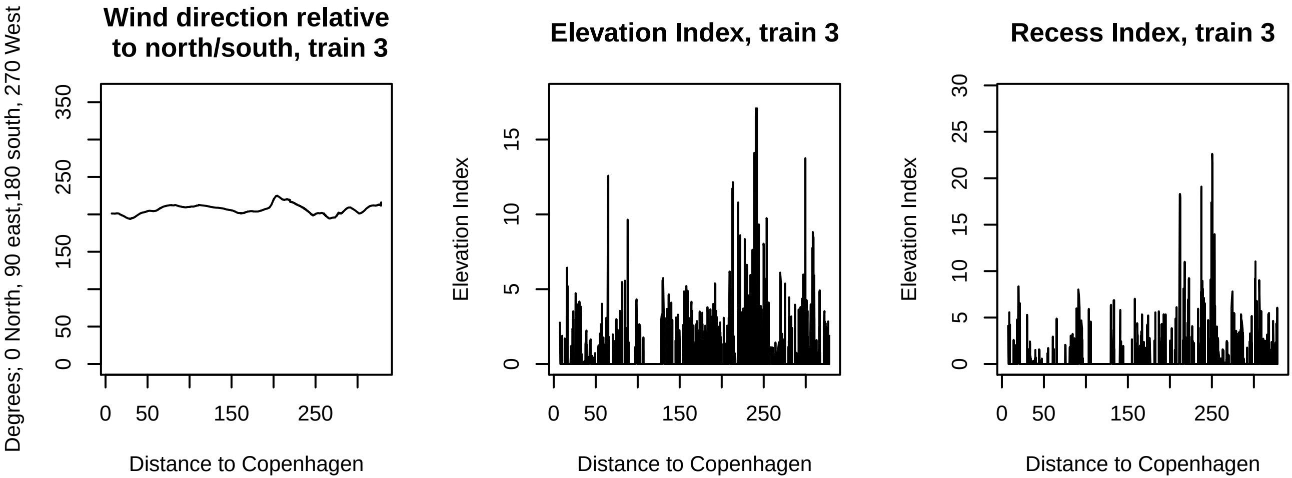


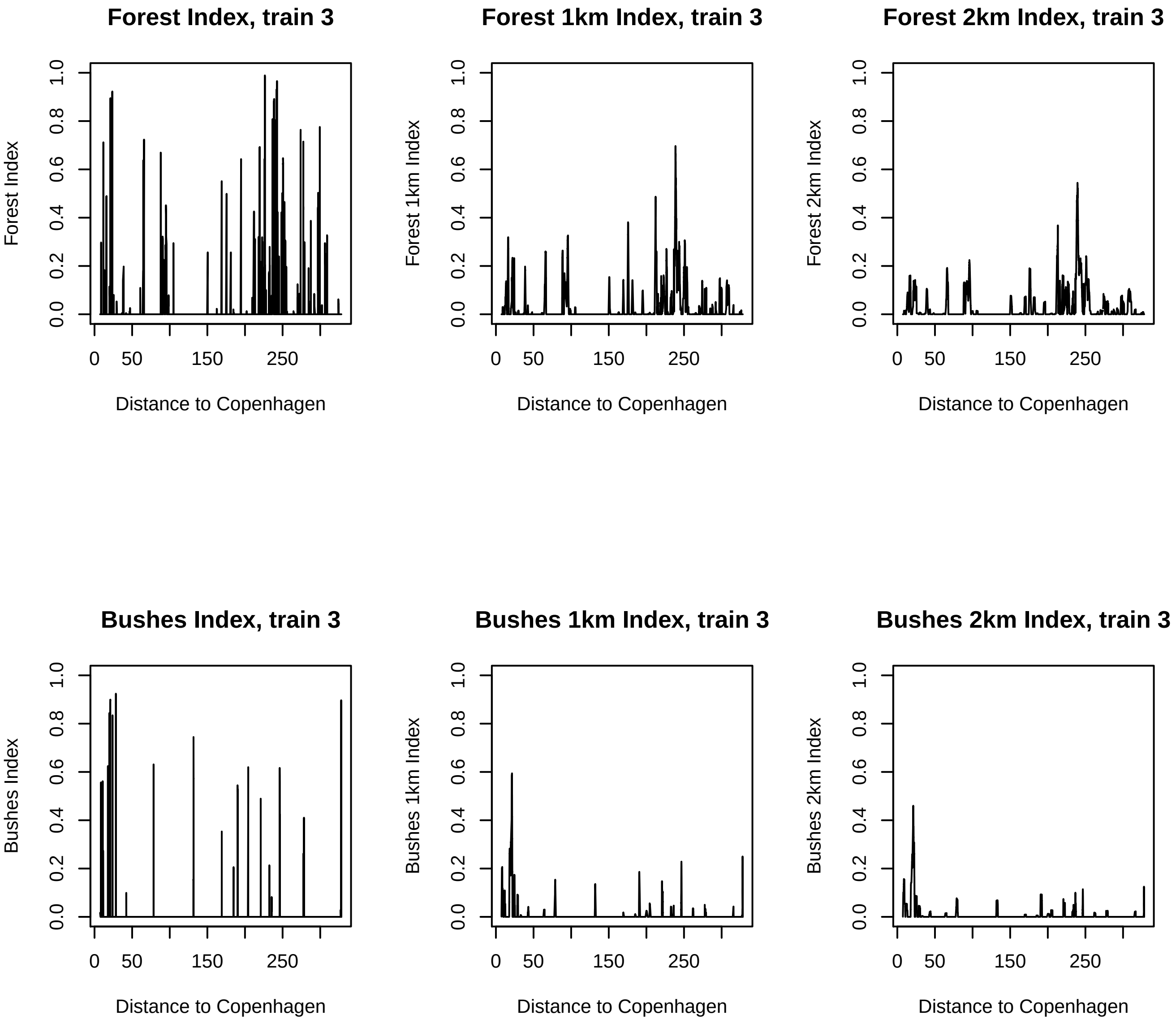

Wind direction relative to north/south, train 1
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 1
Elevation Index
0
5
10
15
Recess Index, train 1
20
25
30

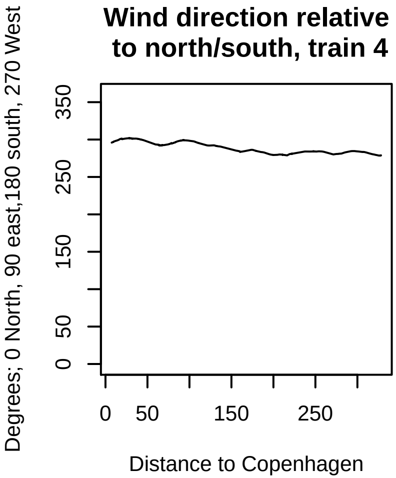

Forest Index, train 1
Forest Index
Distance to Copenhagen
Forest 1km Index, train 1
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 1
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 1
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 1
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 1
Bushes 2km Index
Distance to Copenhagen

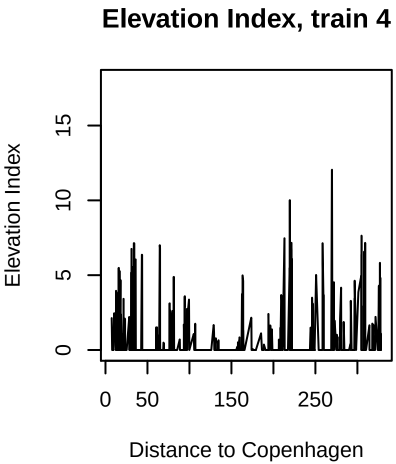

Wind direction relative
to north/south, train 2
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 2
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 2
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

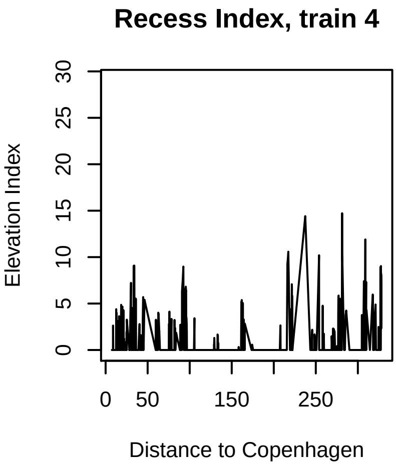

Forest Index, train 2
Forest Index
Distance to Copenhagen
Forest 1km Index, train 2
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 2
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 2
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 2
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 2
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

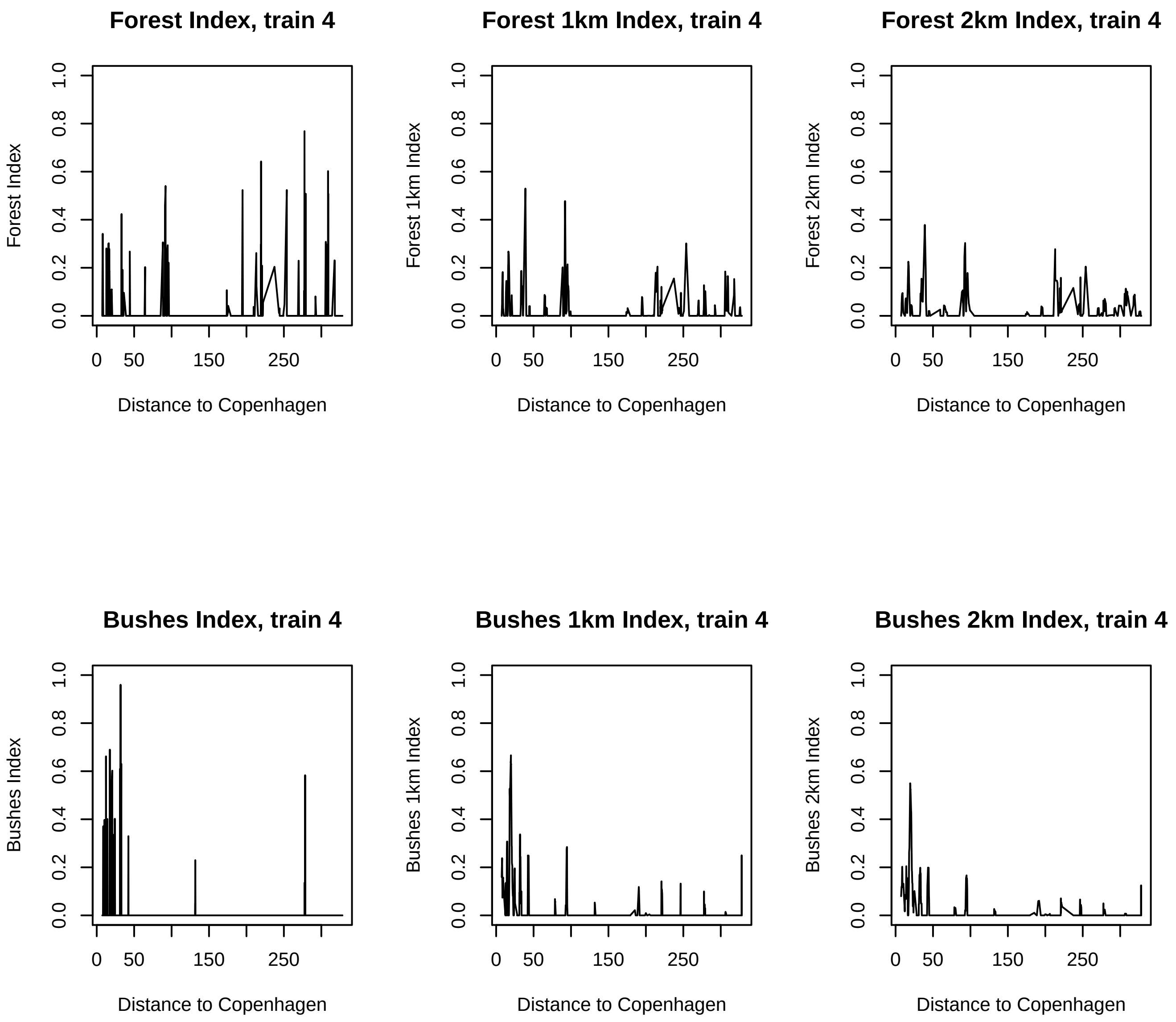

Wind direction relative to north/south, train 3
Degrees; 0 North, 90 east,180 south, 270 West
Distance to Copenhagen
Elevation Index, train 3
Elevation Index
Distance to Copenhagen
Recess Index, train 3
Elevation Index
Distance to Copenhagen

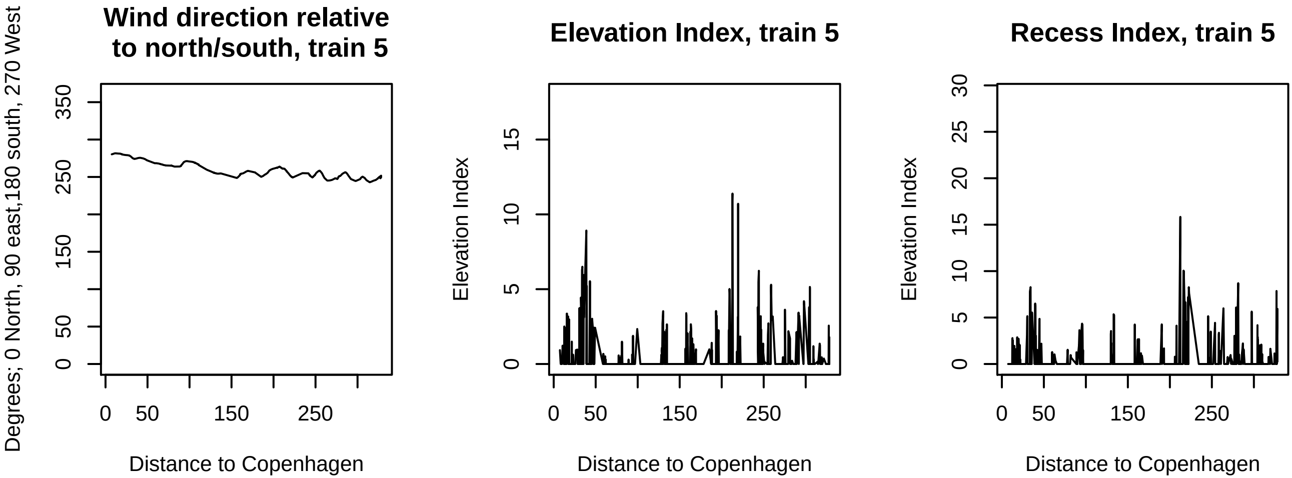

Forest Index, train 3
Forest Index
Distance to Copenhagen
Forest 1km Index, train 3
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 3
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 3
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 3
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 3
Bushes 2km Index
Distance to Copenhagen

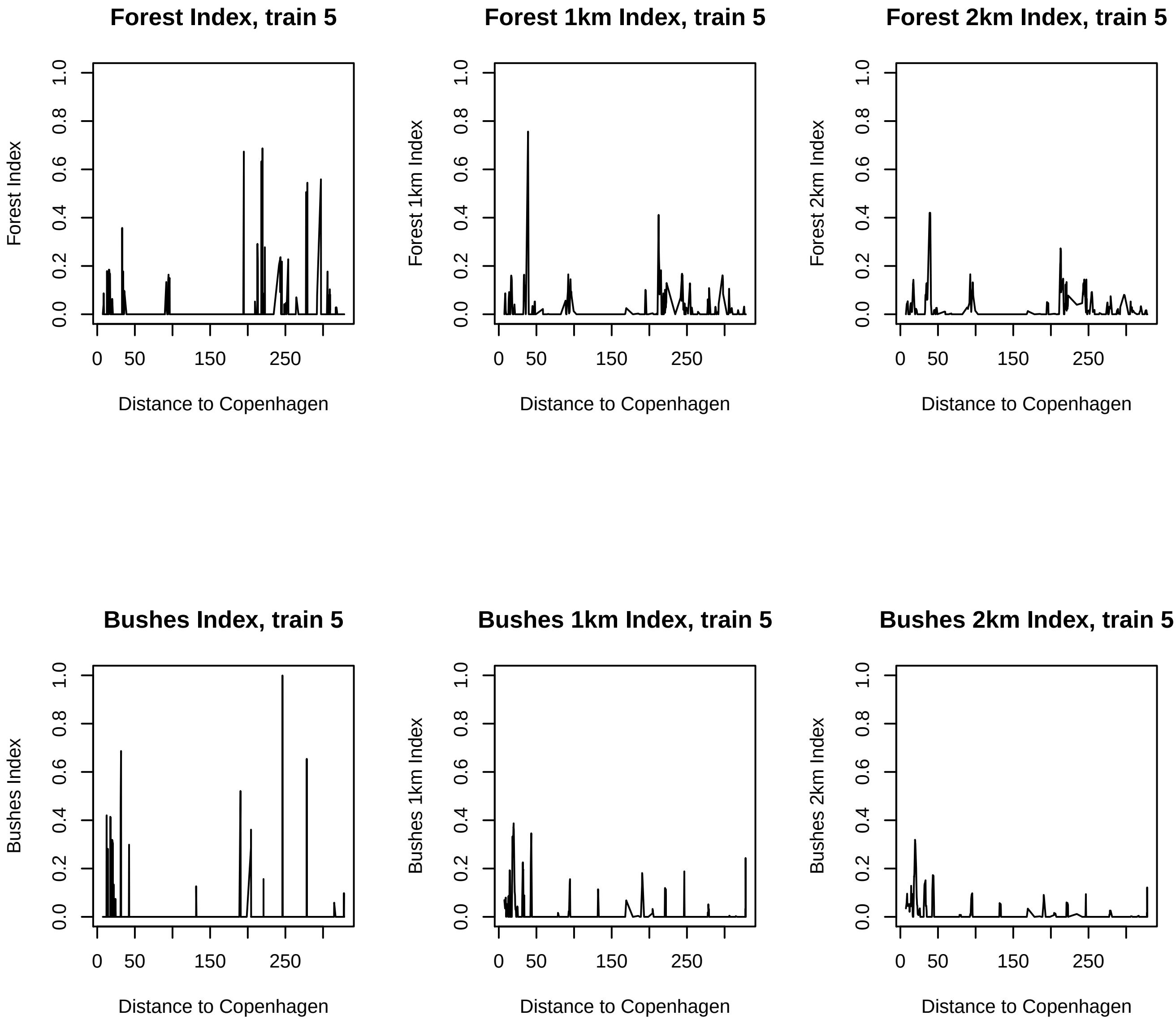

Wind direction relative to north/south, train 4
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
0
50
150
250
Distance to Copenhagen

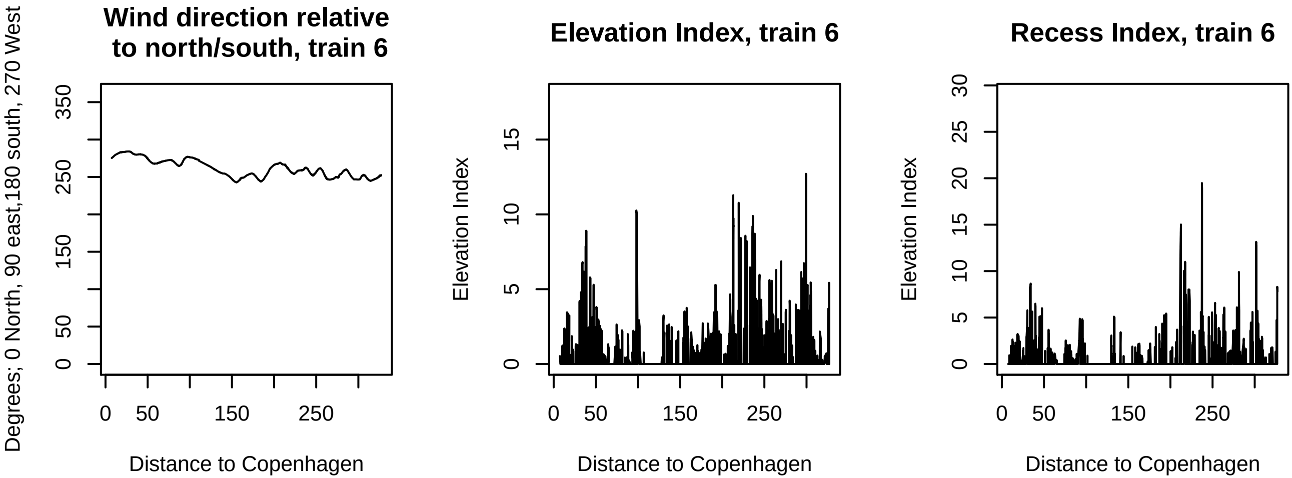

Elevation Index, train 4
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen

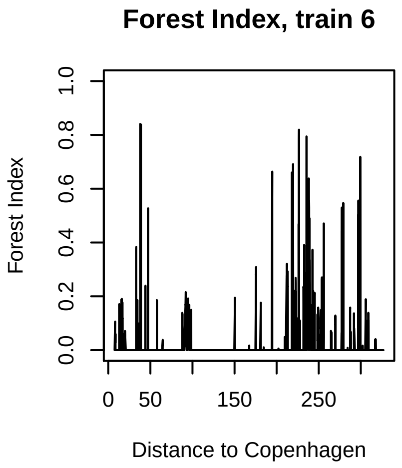

Recess Index, train 4
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

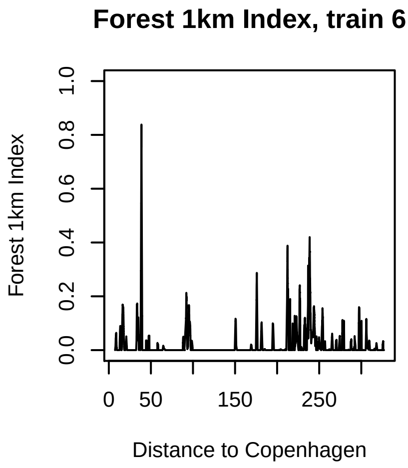

Forest Index, train 4
Forest Index
Distance to Copenhagen
Forest 1km Index, train 4
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 4
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 4
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 4
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 4
Bushes 2km Index
Distance to Copenhagen

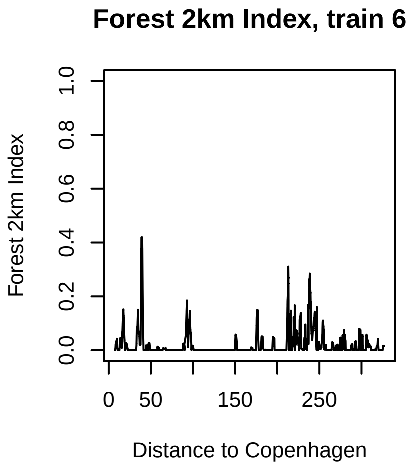

Wind direction relative to north/south, train 5
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 5
Elevation Index
0
5
10
15
Distance to Copenhagen
Recess Index, train 5
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250

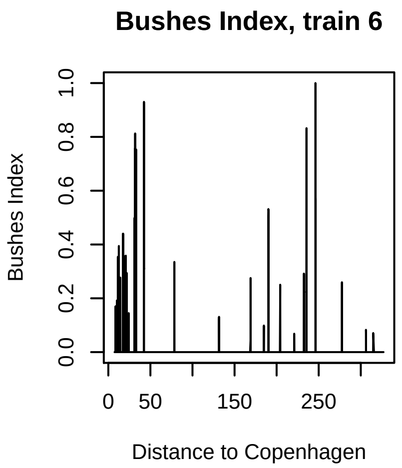

Forest Index, train 5
Forest Index
Distance to Copenhagen
Forest 1km Index, train 5
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 5
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 5
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 5
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 5
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

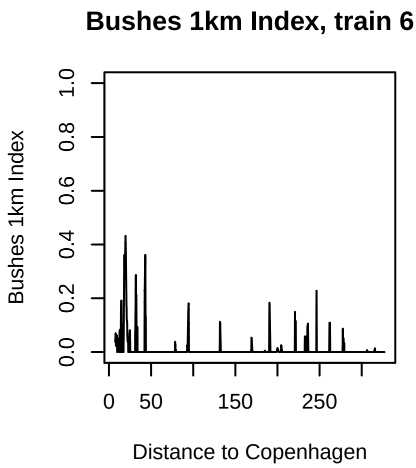

Wind direction relative to north/south, train 6
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 6
Elevation Index
5
10
15
Recess Index, train 6
20
25
30

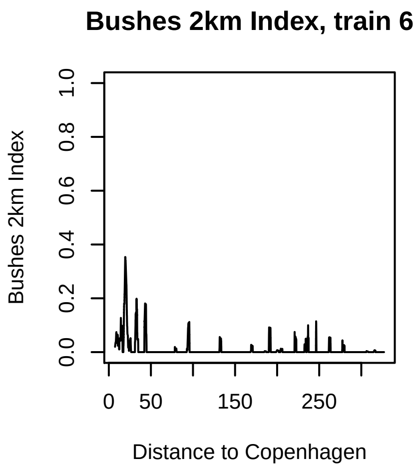

Forest Index, train 6
Forest Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

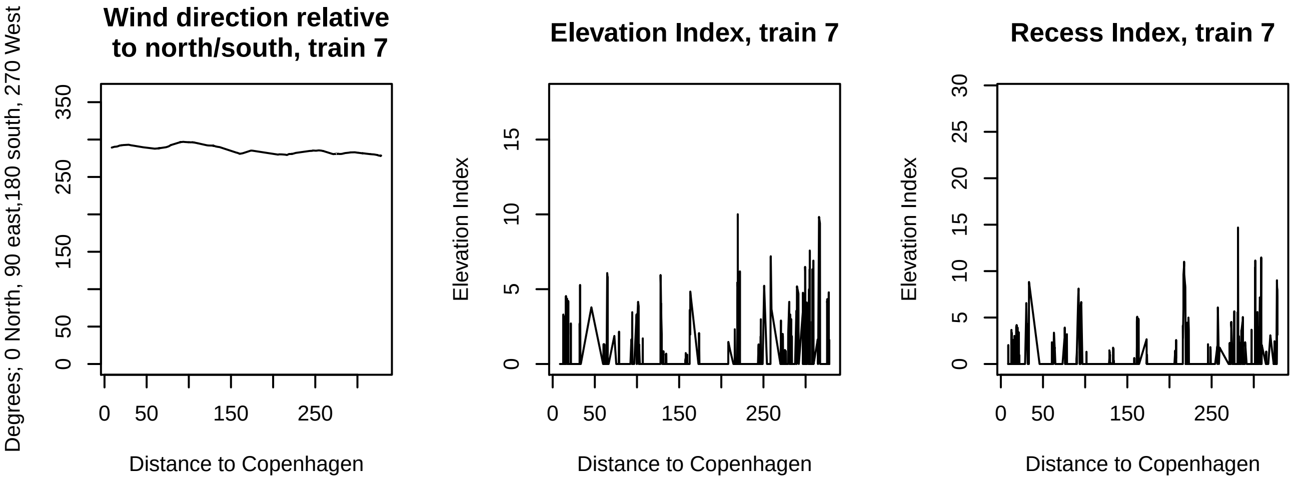

Forest 1km Index, train 6
Forest 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

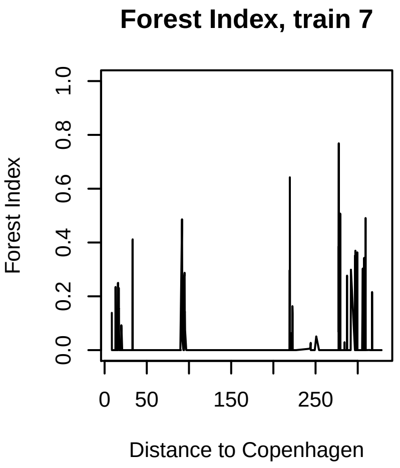

Forest 2km Index, train 6
Forest 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

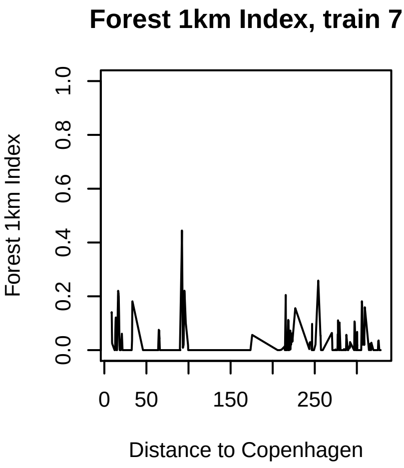

Bushes Index, train 6
Bushes Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

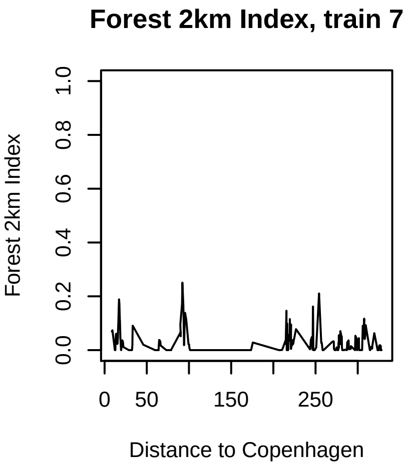

Bushes 1km Index, train 6
Bushes 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

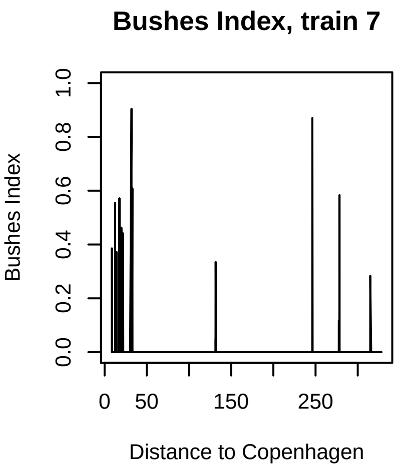

Bushes 2km Index, train 6
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

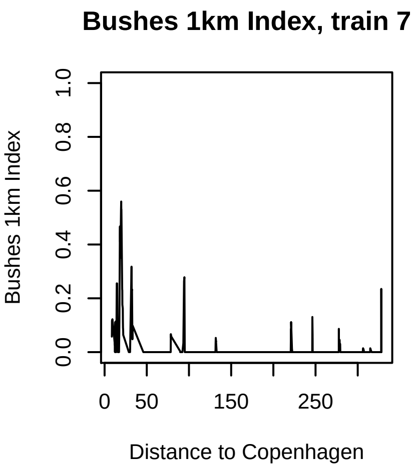

Wind direction relative
to north/south, train 7
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 7
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 7
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

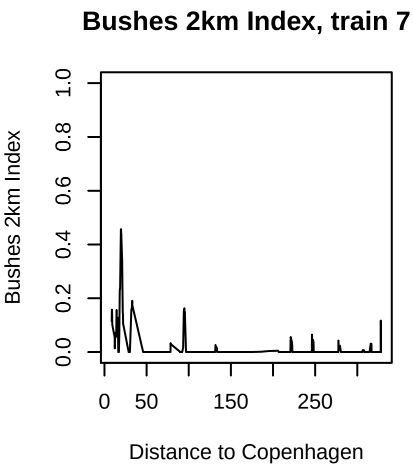

Forest Index, train 7
Forest Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

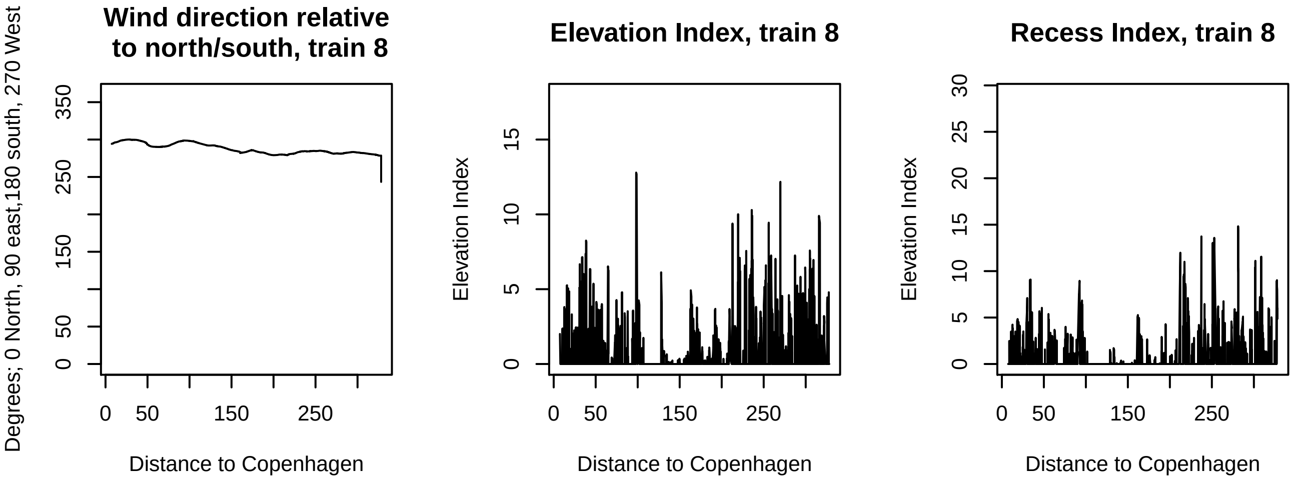

Forest 1km Index, train 7
Forest 1km Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

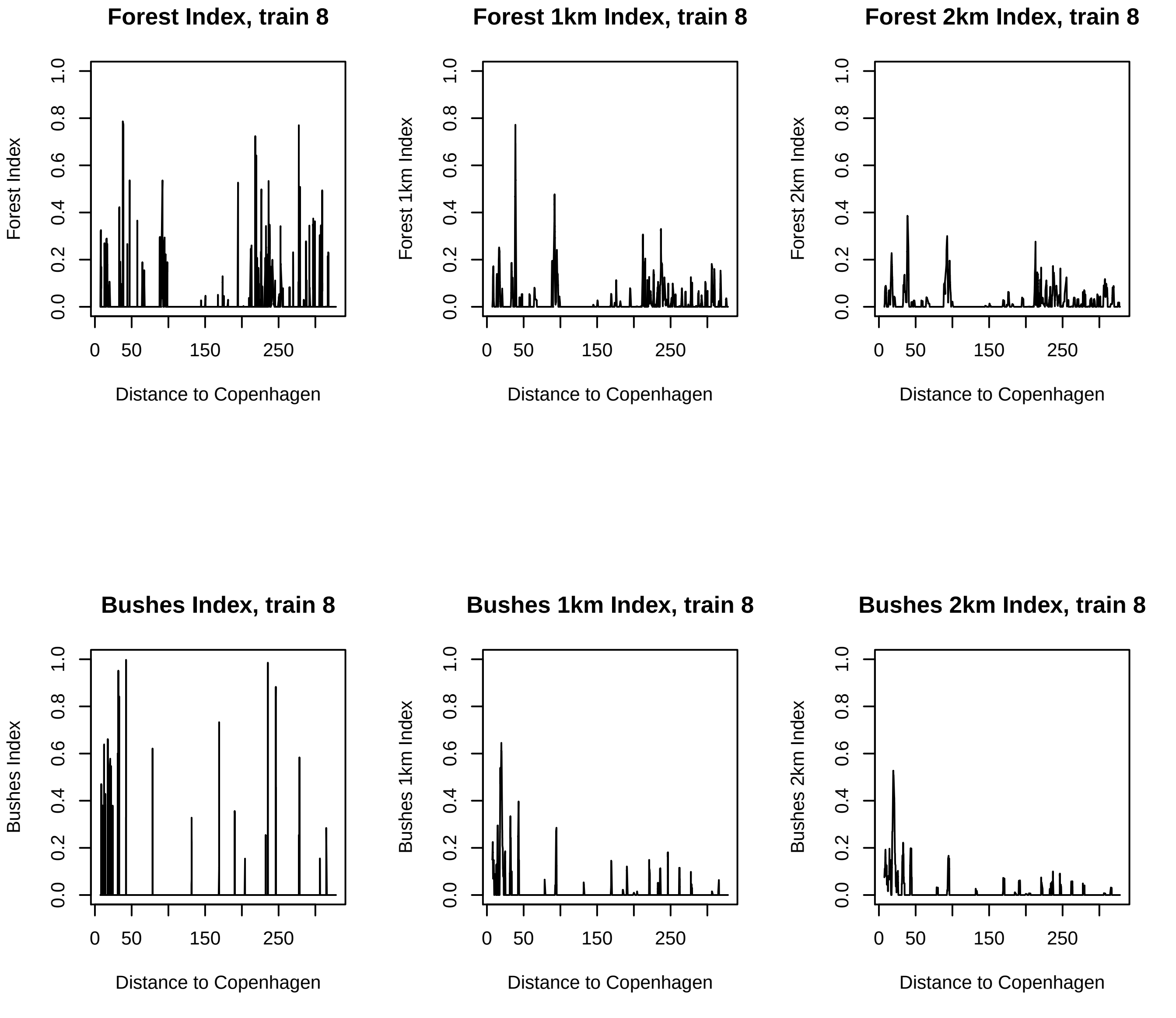

Forest 2km Index, train 7
Forest 2km Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

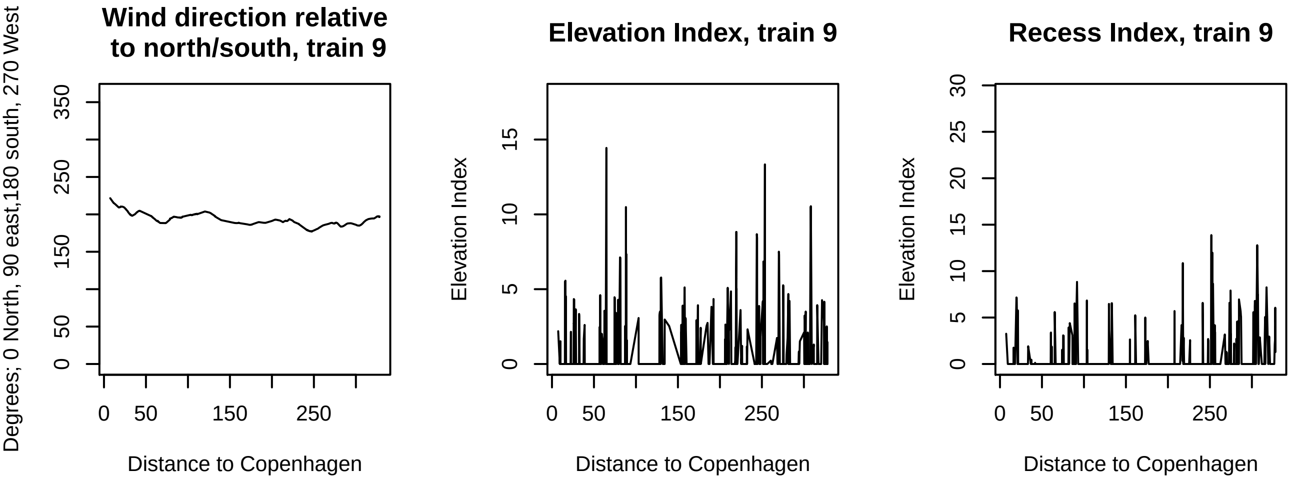

Bushes Index, train 7
Bushes Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

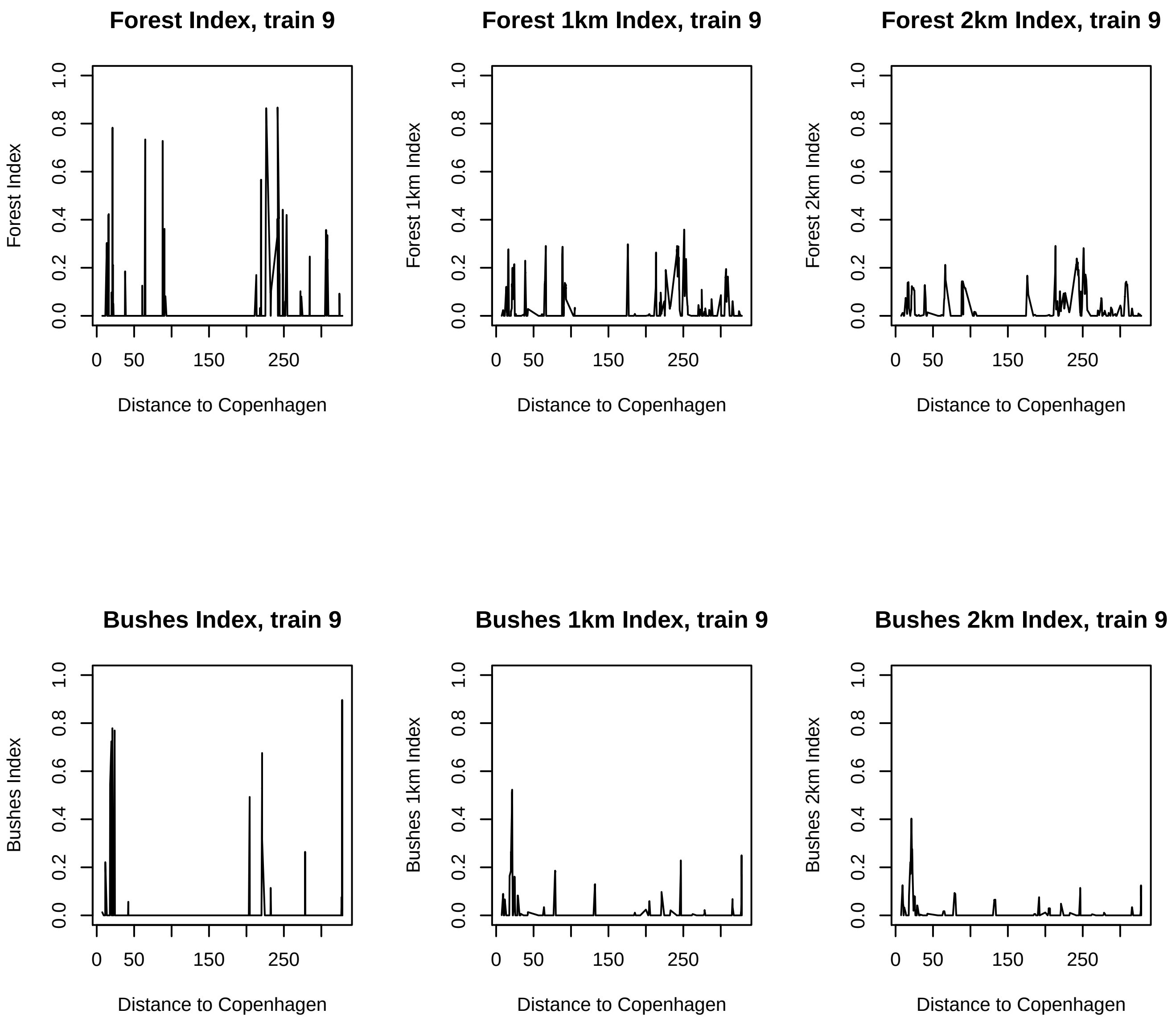

Bushes 1km Index, train 7
Bushes 1km Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

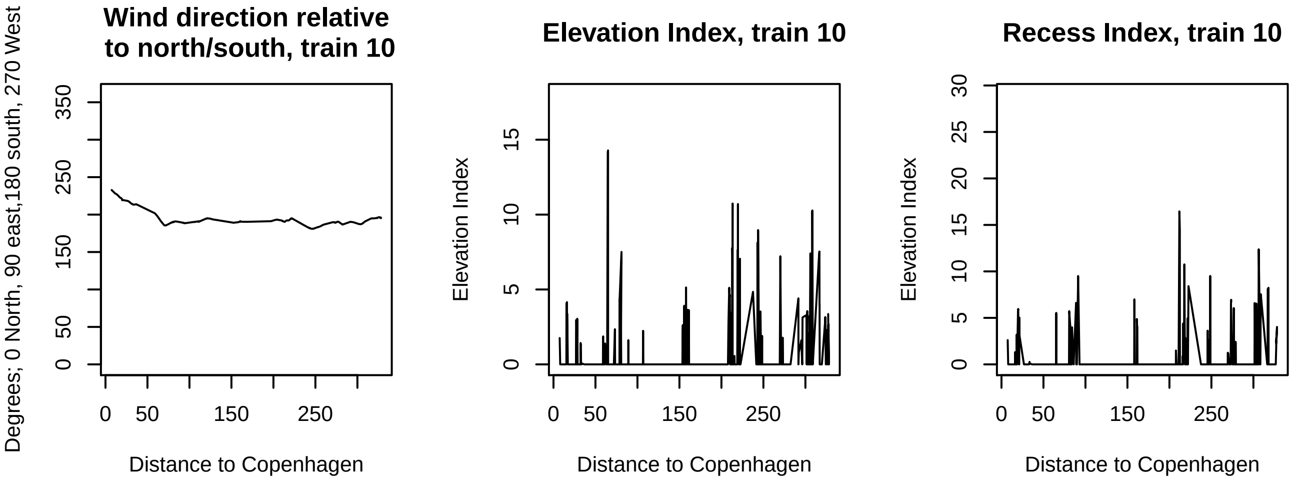

Bushes 2km Index, train 7
Bushes 2km Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

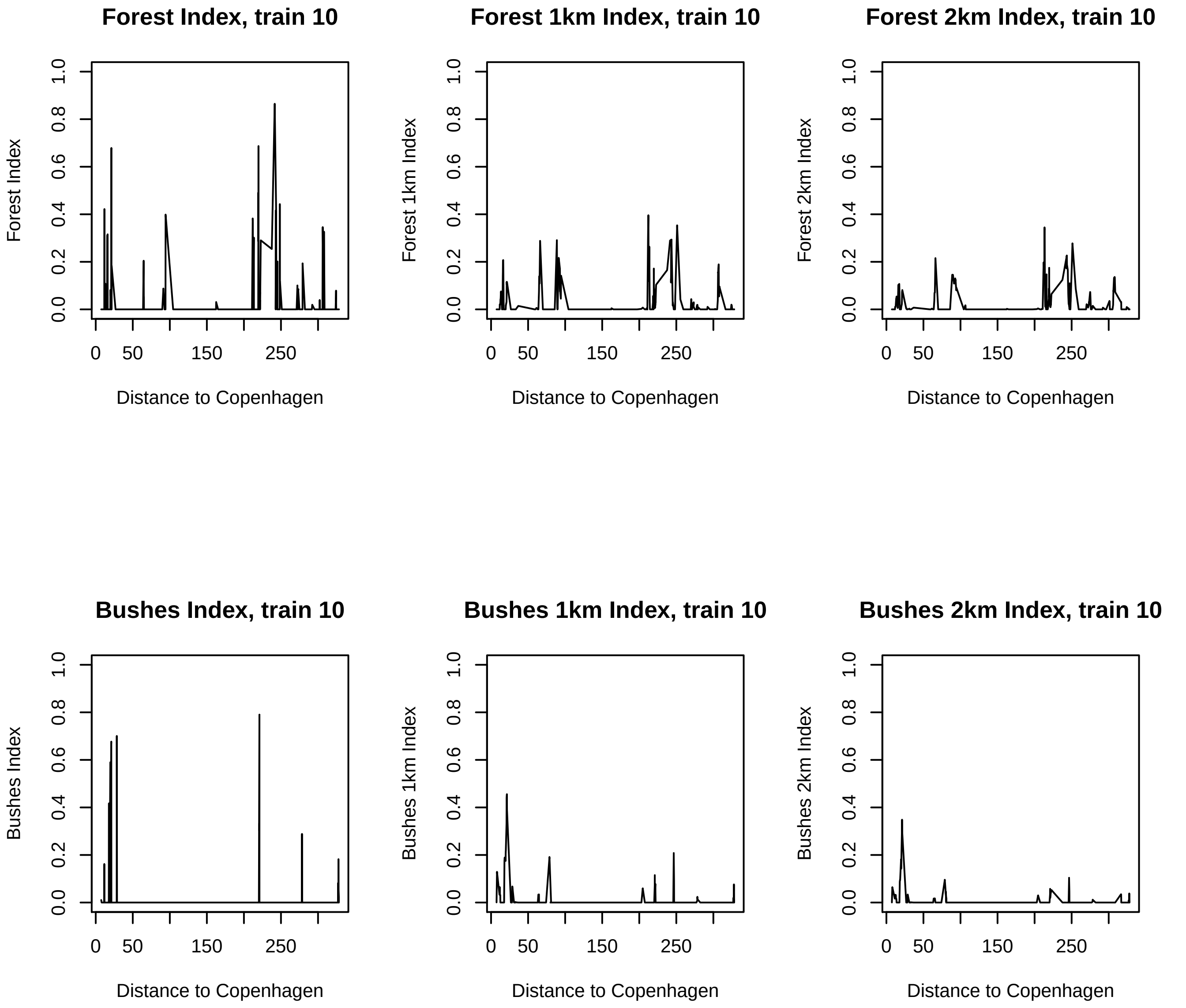

Wind direction relative to north/south, train 8
Degrees; 0 North, 90 east,180 south, 270 West
Distance to Copenhagen
Elevation Index, train 8
Elevation Index
Distance to Copenhagen
Recess Index, train 8
Elevation Index
Distance to Copenhagen

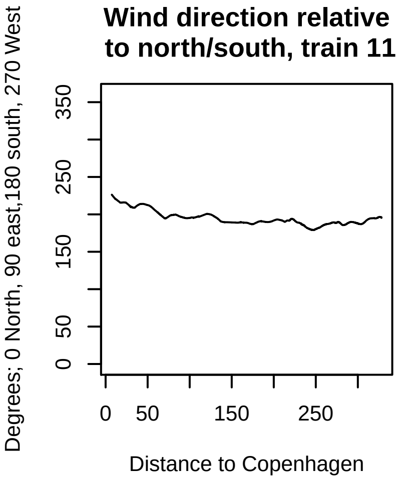

Forest Index, train 8
Forest Index
Forest 1km Index, train 8
Forest 1km Index
Forest 2km Index, train 8
Forest 2km Index
Bushes Index, train 8
Bushes Index
Bushes 1km Index, train 8
Bushes 1km Index
Bushes 2km Index, train 8
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen


Wind direction relative to north/south, train 9
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 9
Elevation Index
5
10
15
Recess Index, train 9
20
25
30

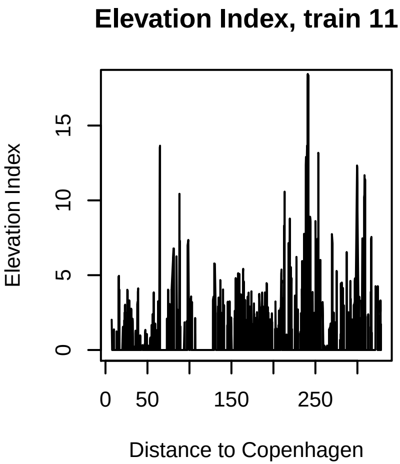

Forest Index, train 9
Forest Index
Distance to Copenhagen
Forest 1km Index, train 9
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 9
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 9
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 9
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 9
Bushes 2km Index
Distance to Copenhagen


Wind direction relative to north/south, train 10
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 10
Elevation Index
0
5
10
15
Recess Index, train 10
Elevation Index
0
5
10
15
20
25
30

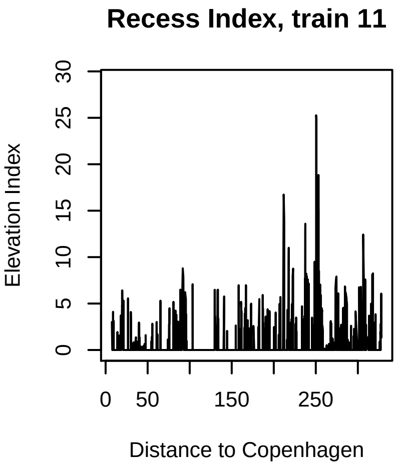

Forest Index, train 10
Forest Index
Distance to Copenhagen
Forest 1km Index, train 10
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 10
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 10
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 10
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 10
Bushes 2km Index
Distance to Copenhagen



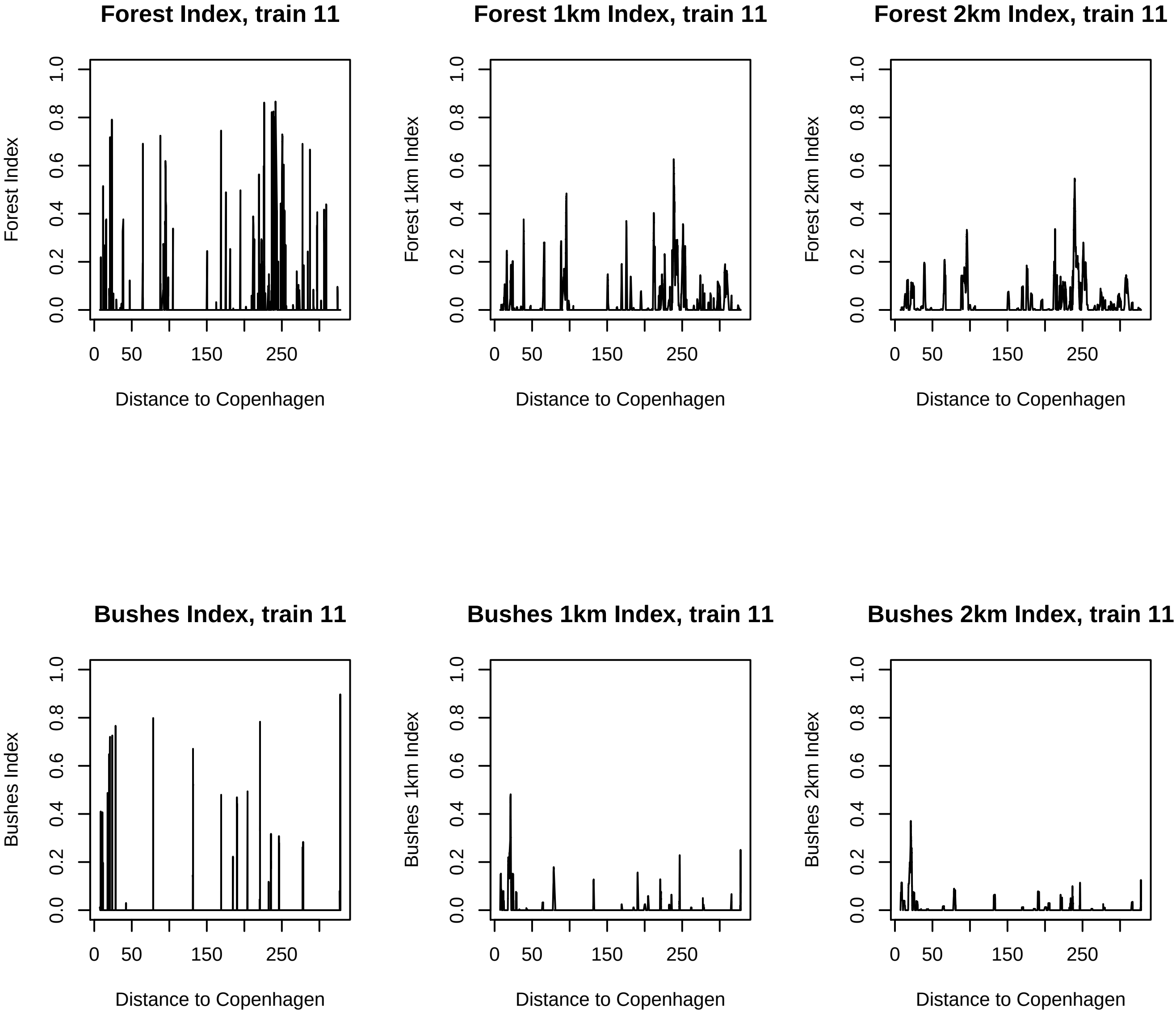
Wind direction relative to north/south, train 11
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
0
50
150
250
Distance to Copenhagen

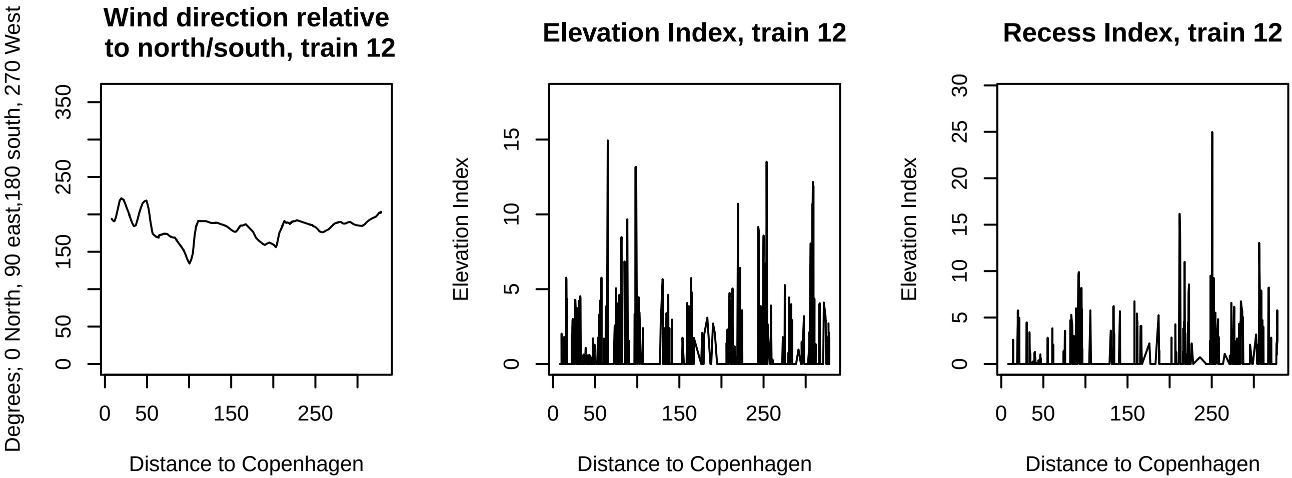


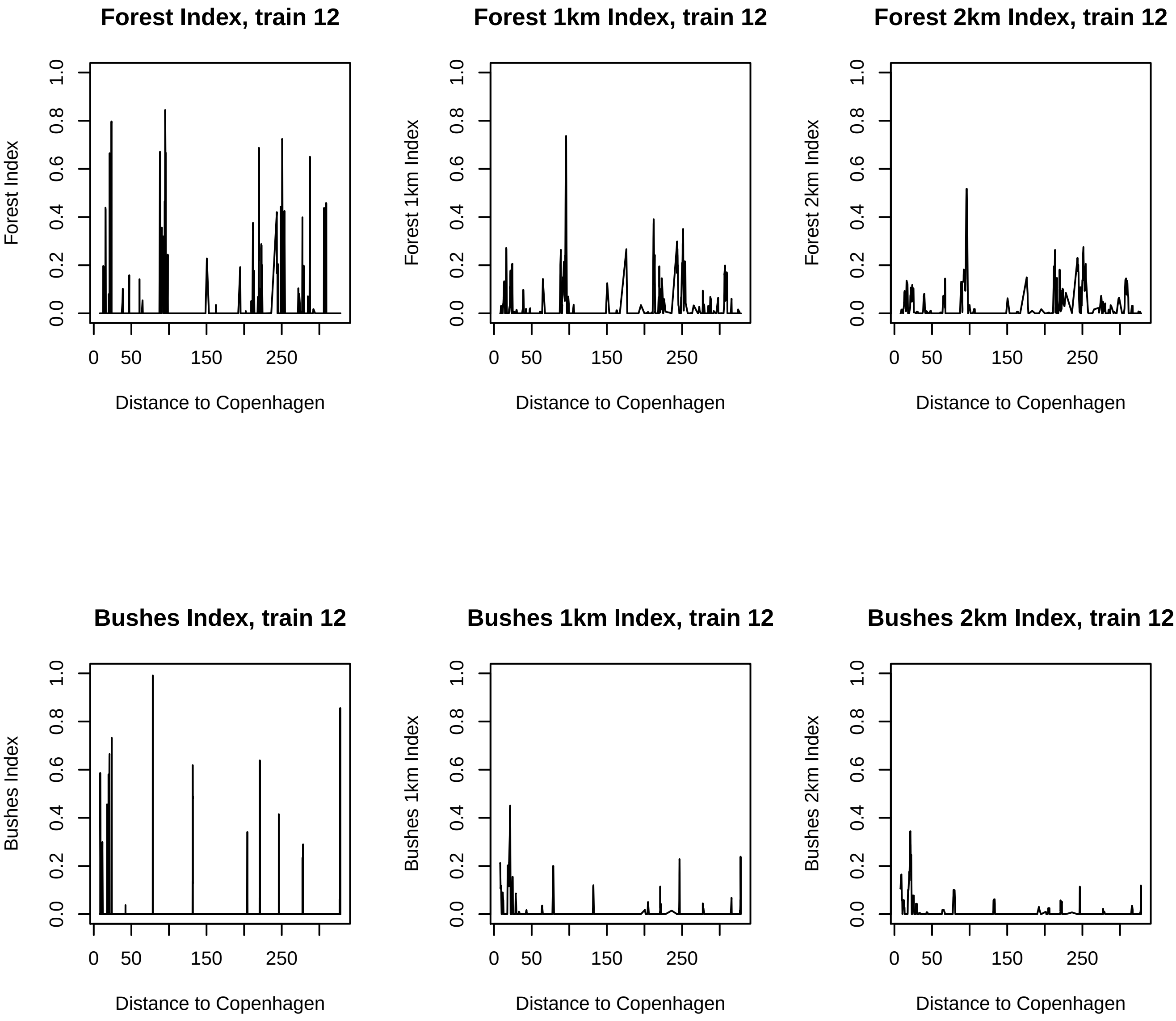
Elevation Index, train 11
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen

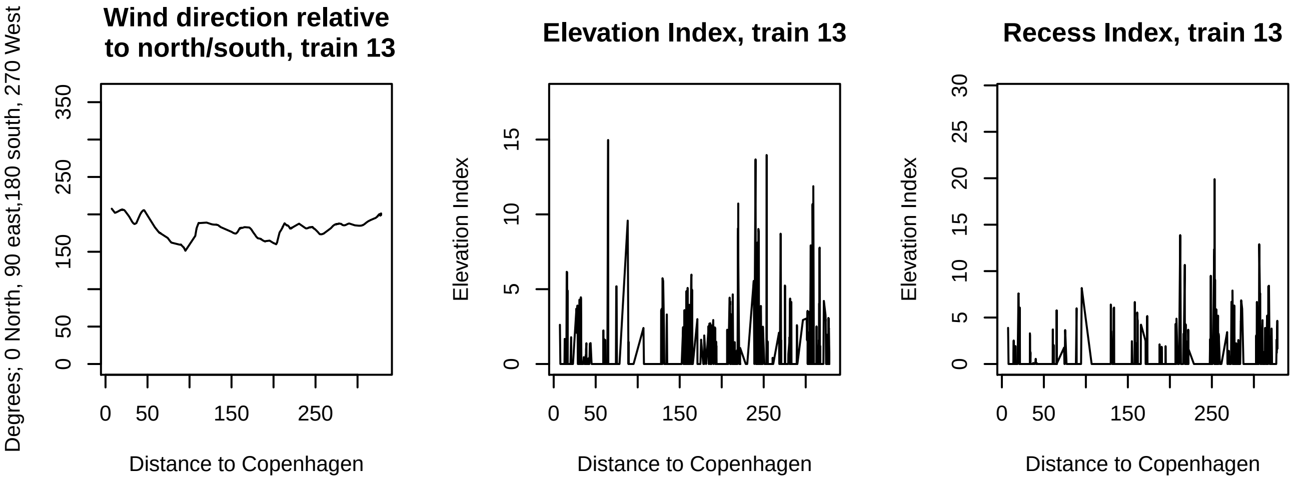


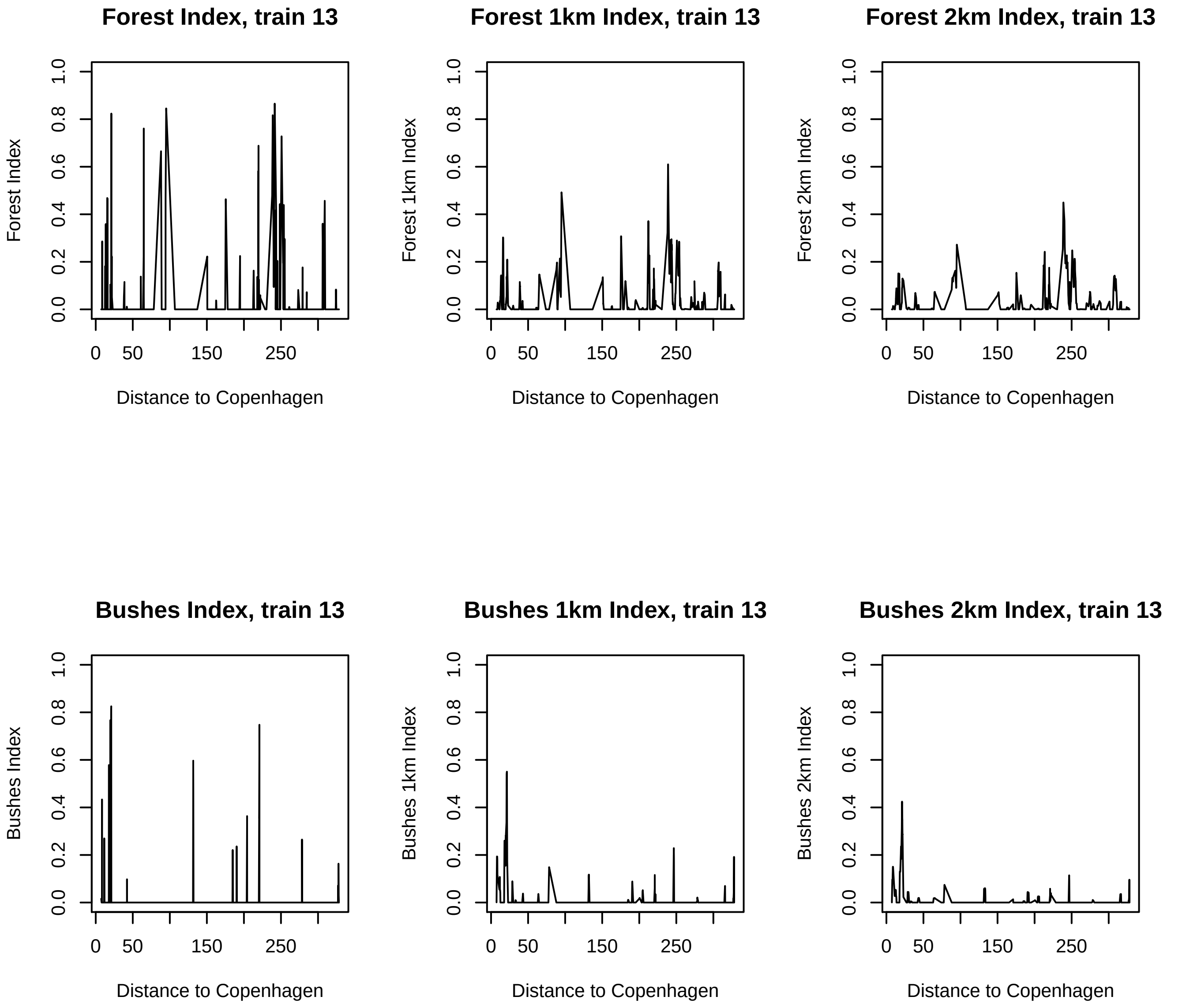
Recess Index, train 11
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

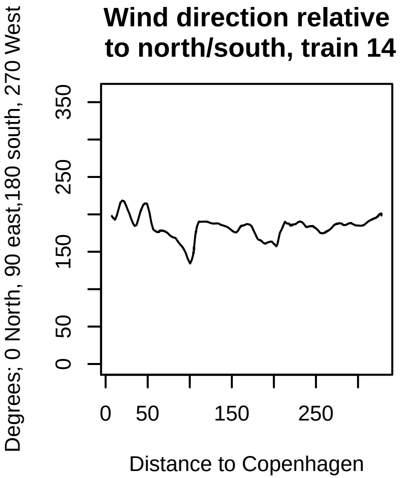

Forest Index, train 11
Forest Index
Distance to Copenhagen
Forest 1km Index, train 11
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 11
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 11
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 11
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 11
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

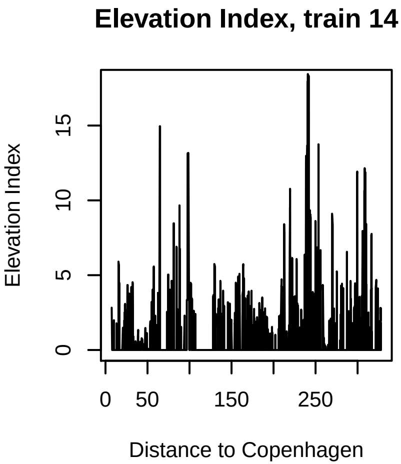

Wind direction relative to north/south, train 12
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 12
Elevation Index
0
5
10
15
Recess Index, train 12
0
5
10
15
20
25
30

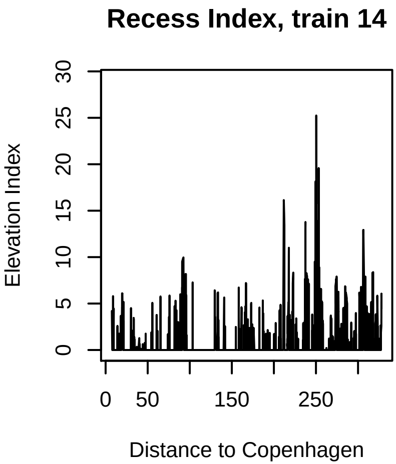

Forest Index, train 12
Forest Index
Distance to Copenhagen
Forest 1km Index, train 12
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 12
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 12
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 12
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 12
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

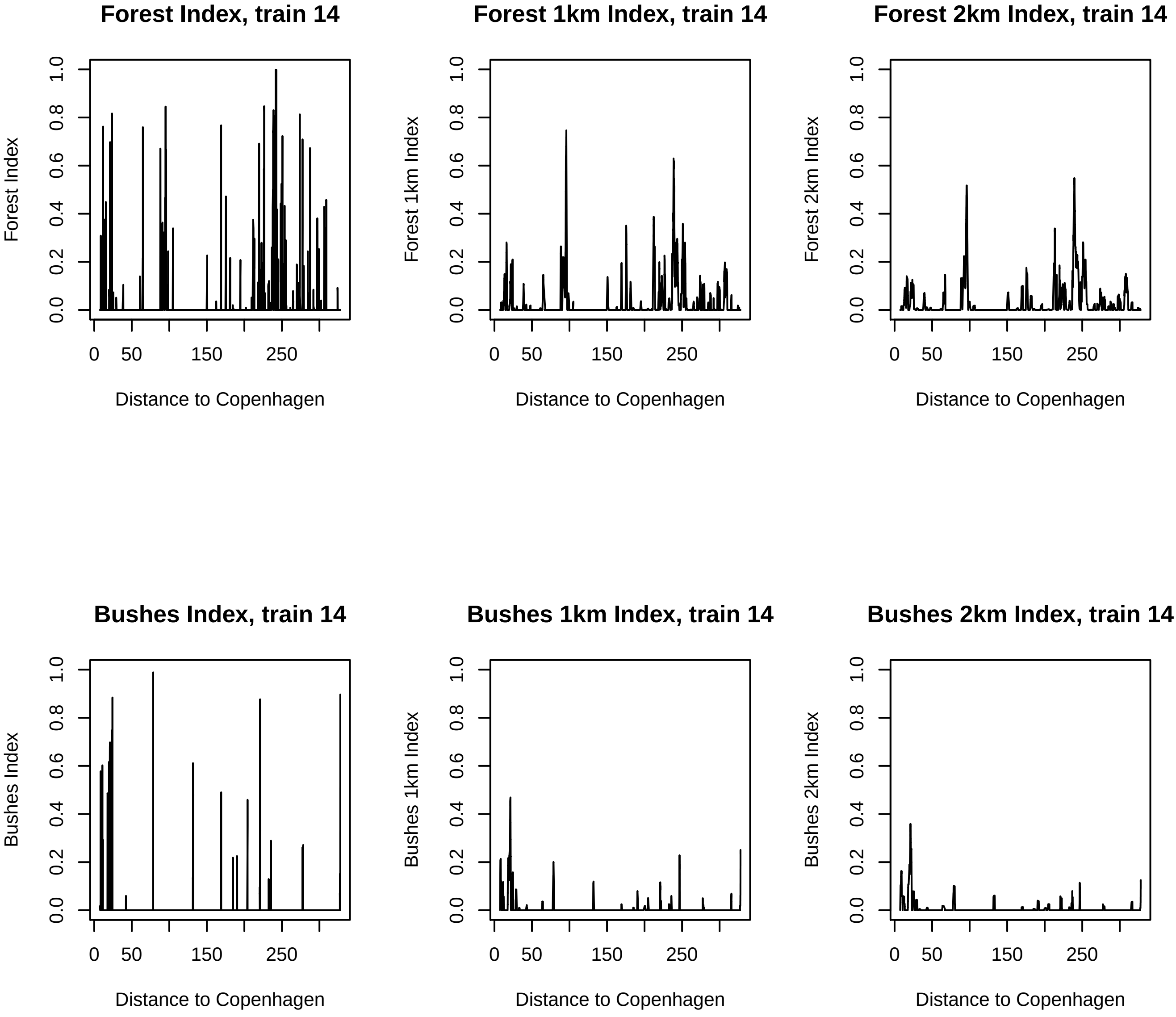

Wind direction relative
to north/south, train 13
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 13
Elevation Index
0
5
10
15
Distance to Copenhagen
Recess Index, train 13
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen

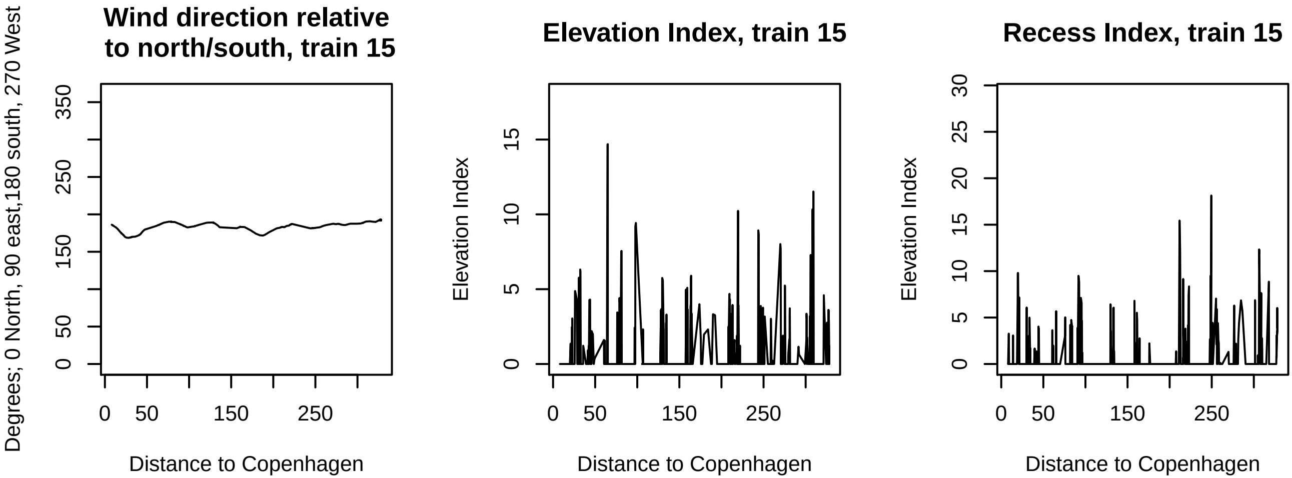

Forest Index, train 13
Forest Index
Distance to Copenhagen
Forest 1km Index, train 13
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 13
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 13
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 13
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 13
Bushes 2km Index
Distance to Copenhagen

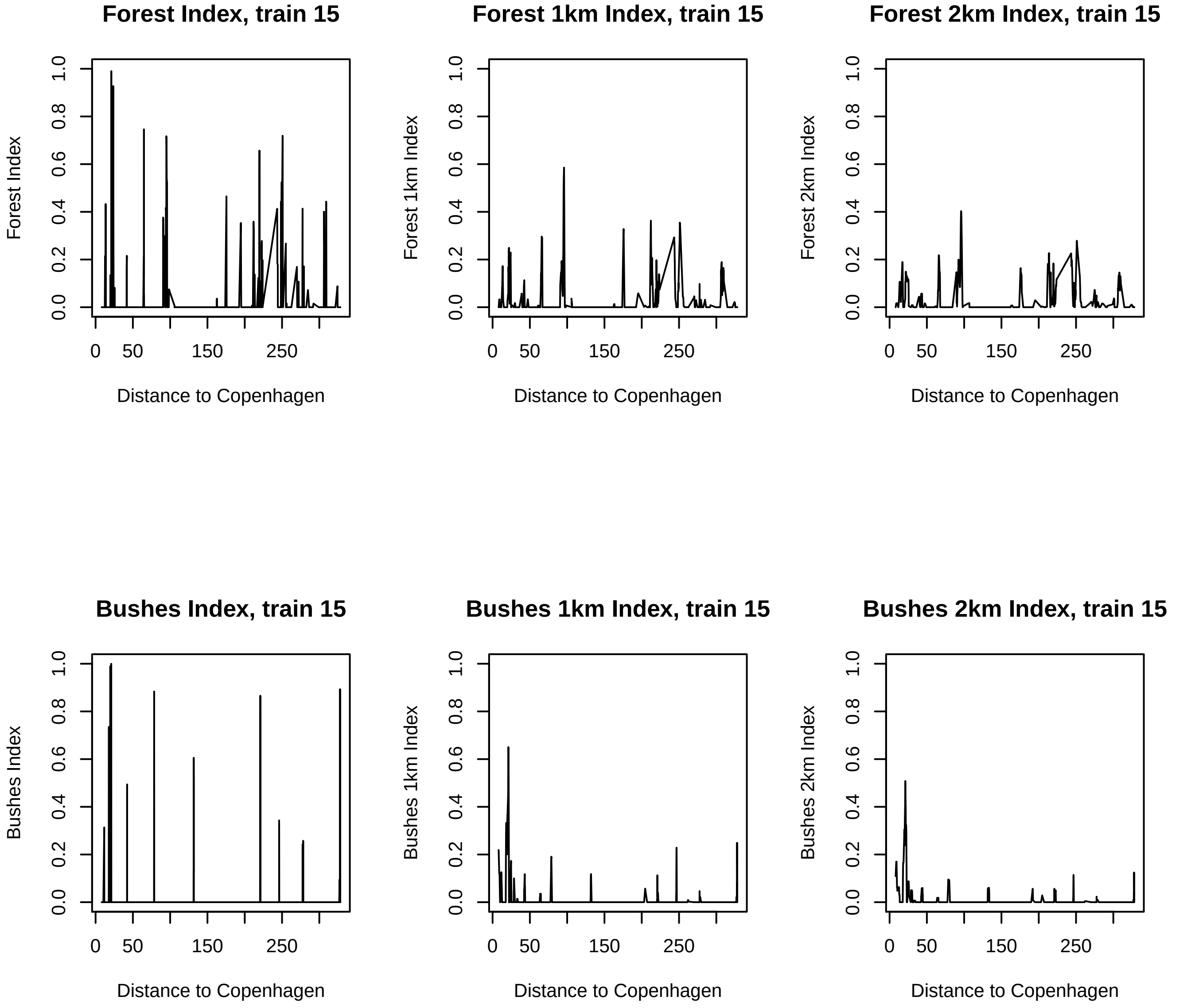

Wind direction relative
to north/south, train 14
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen

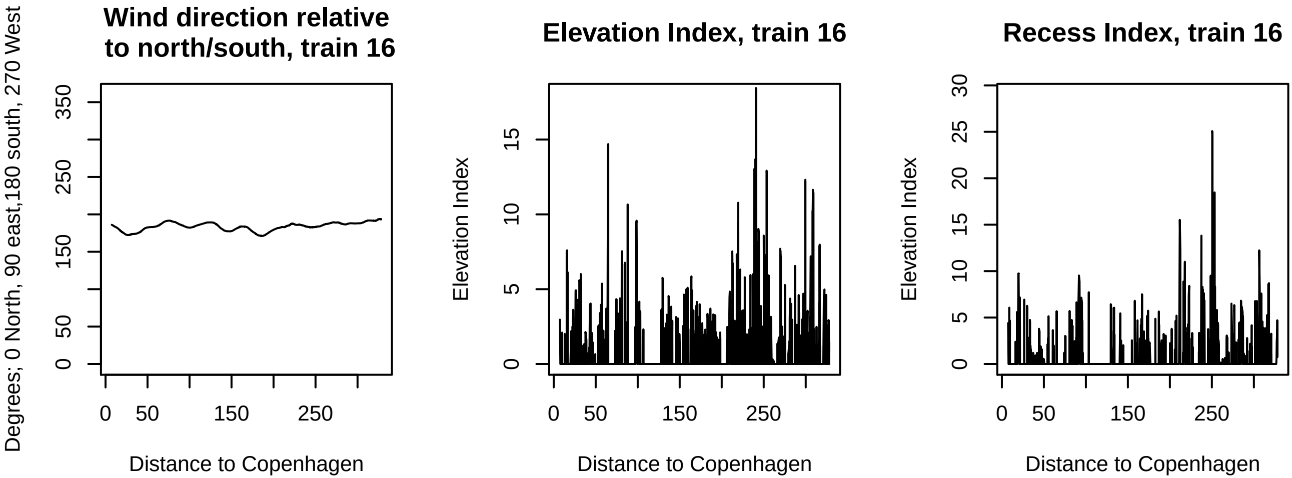

Elevation Index, train 14
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen

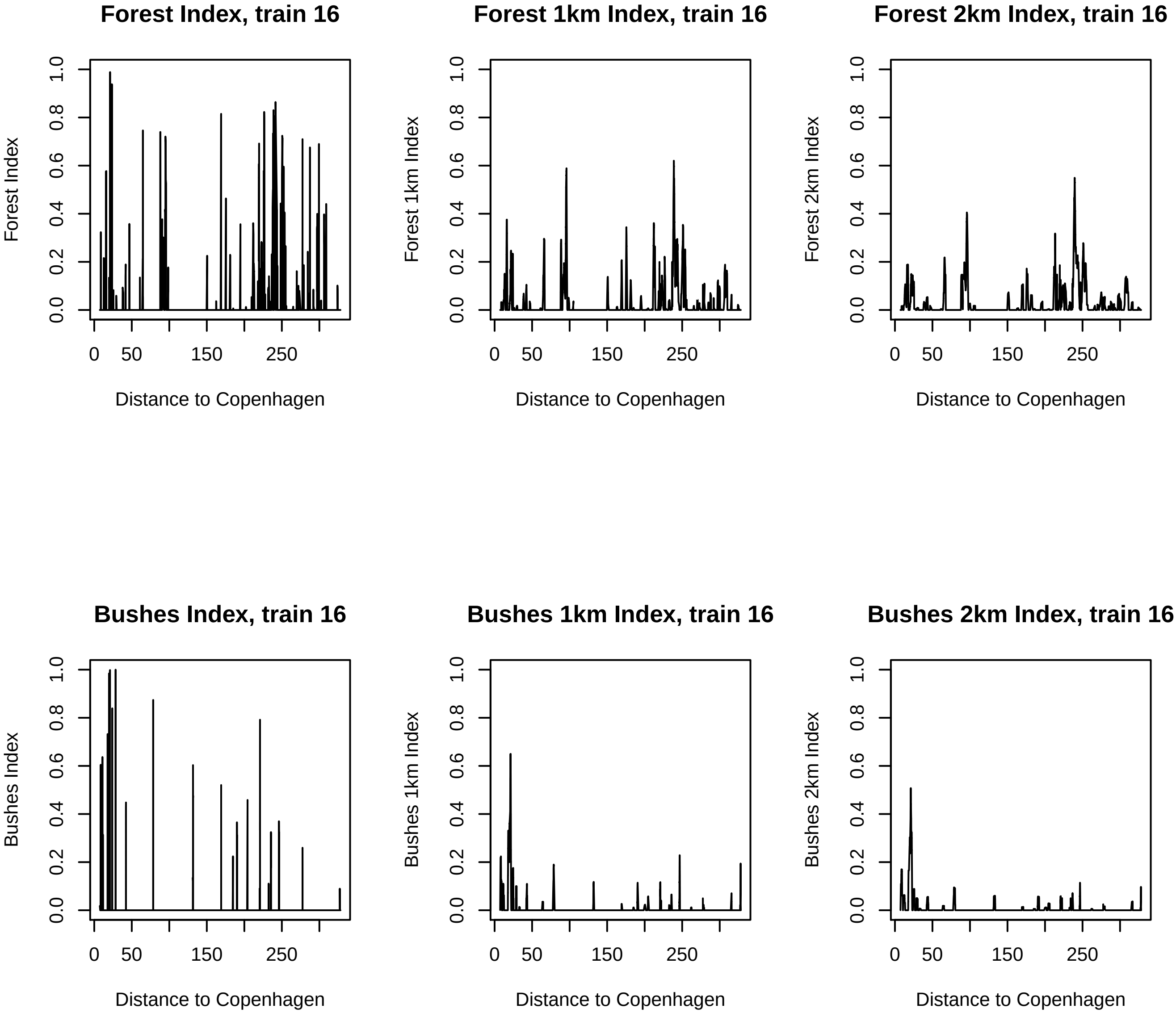

Recess Index, train 14
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

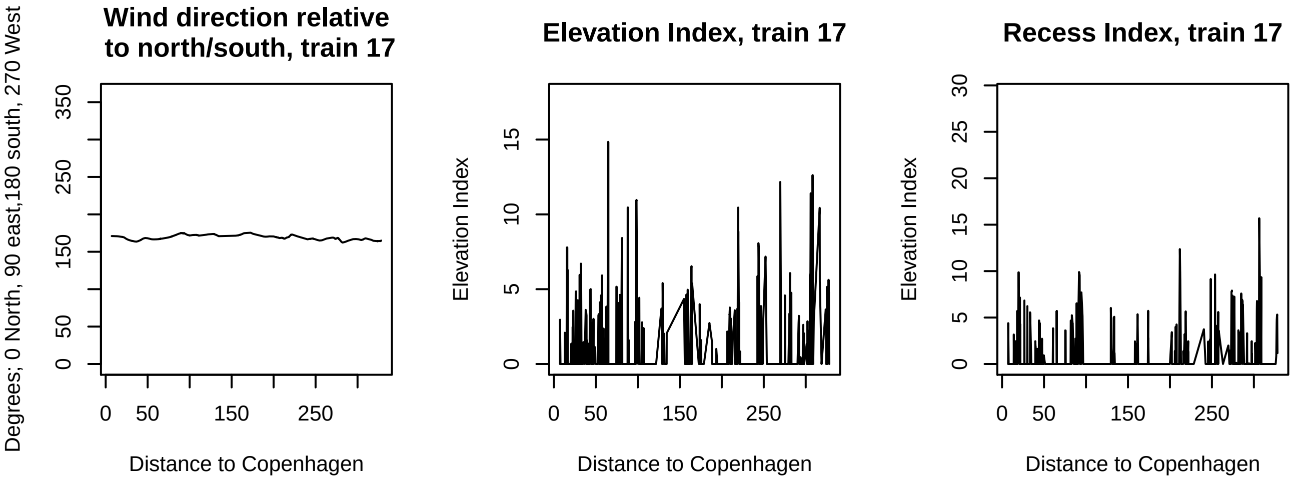

Forest Index, train 14
Forest Index
Forest 1km Index, train 14
Forest 1km Index
Forest 2km Index, train 14
Forest 2km Index
Bushes Index, train 14
Bushes Index
Bushes 1km Index, train 14
Bushes 1km Index
Bushes 2km Index, train 14
Bushes 2km Index
0.0 0.2 0.4 0.6 0.8 1.0
0 50 150 250
Distance to Copenhagen

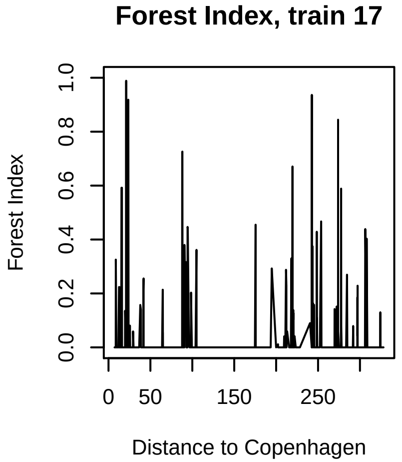

Wind direction relative to north/south, train 15
Degrees; 0 North, 90 east,180 south, 270 West
Distance to Copenhagen
Elevation Index, train 15
Elevation Index
Distance to Copenhagen
Recess Index, train 15
Elevation Index
Distance to Copenhagen

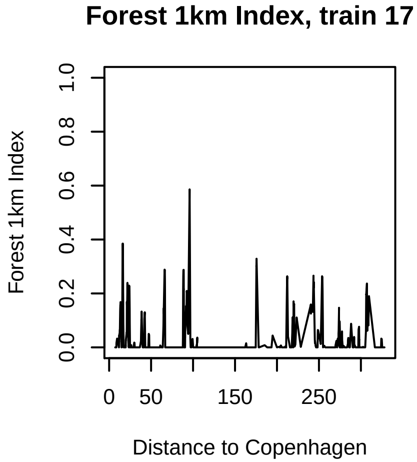

Forest Index, train 15
Forest Index
Distance to Copenhagen
Forest 1km Index, train 15
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 15
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 15
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 15
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 15
Bushes 2km Index
Distance to Copenhagen

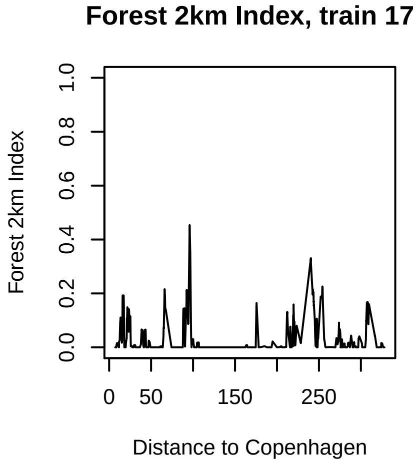

Wind direction relative to north/south, train 16
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 16
Elevation Index
0
5
10
15
Recess Index, train 16
30
25
20

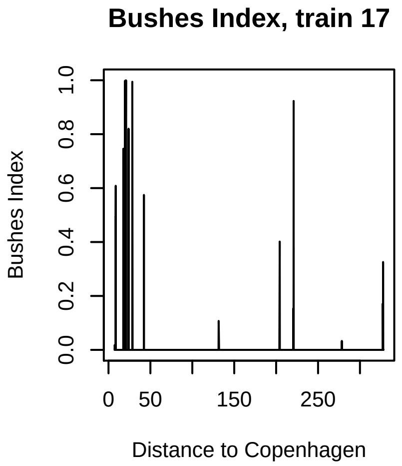

Forest Index, train 16
Forest Index
Distance to Copenhagen
Forest 1km Index, train 16
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 16
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 16
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 16
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 16
Bushes 2km Index
Distance to Copenhagen

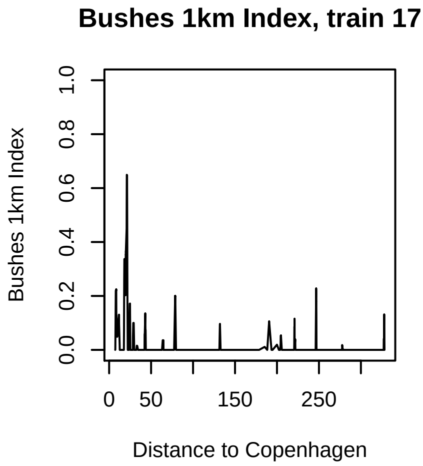

Wind direction relative to north/south, train 17
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 17
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 17
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

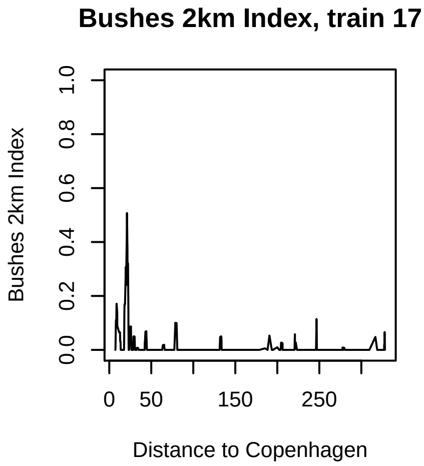

Forest Index, train 17
Forest Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

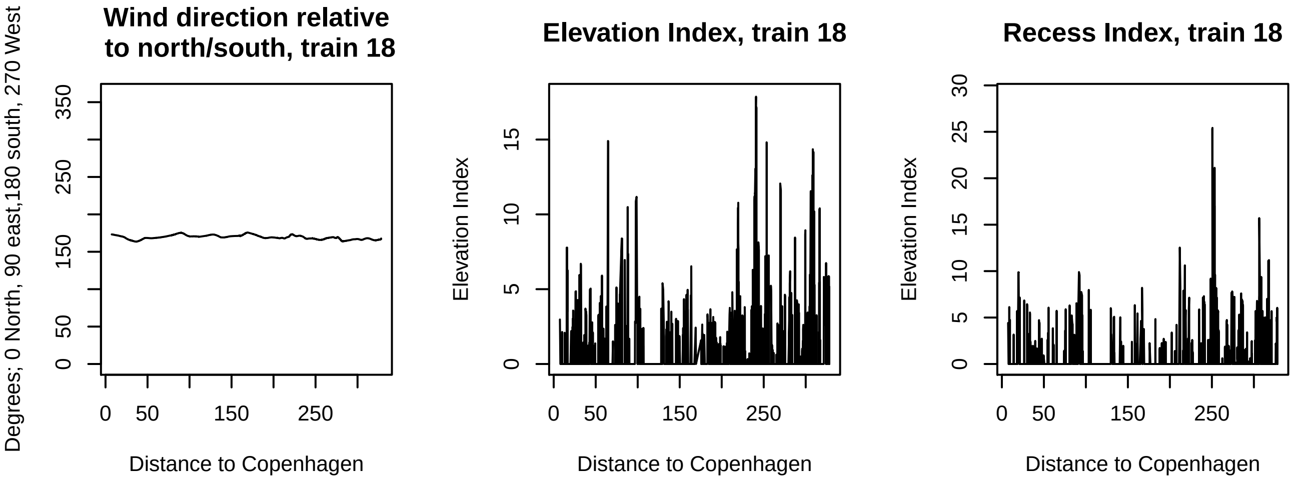

Forest 1km Index, train 17
Forest 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

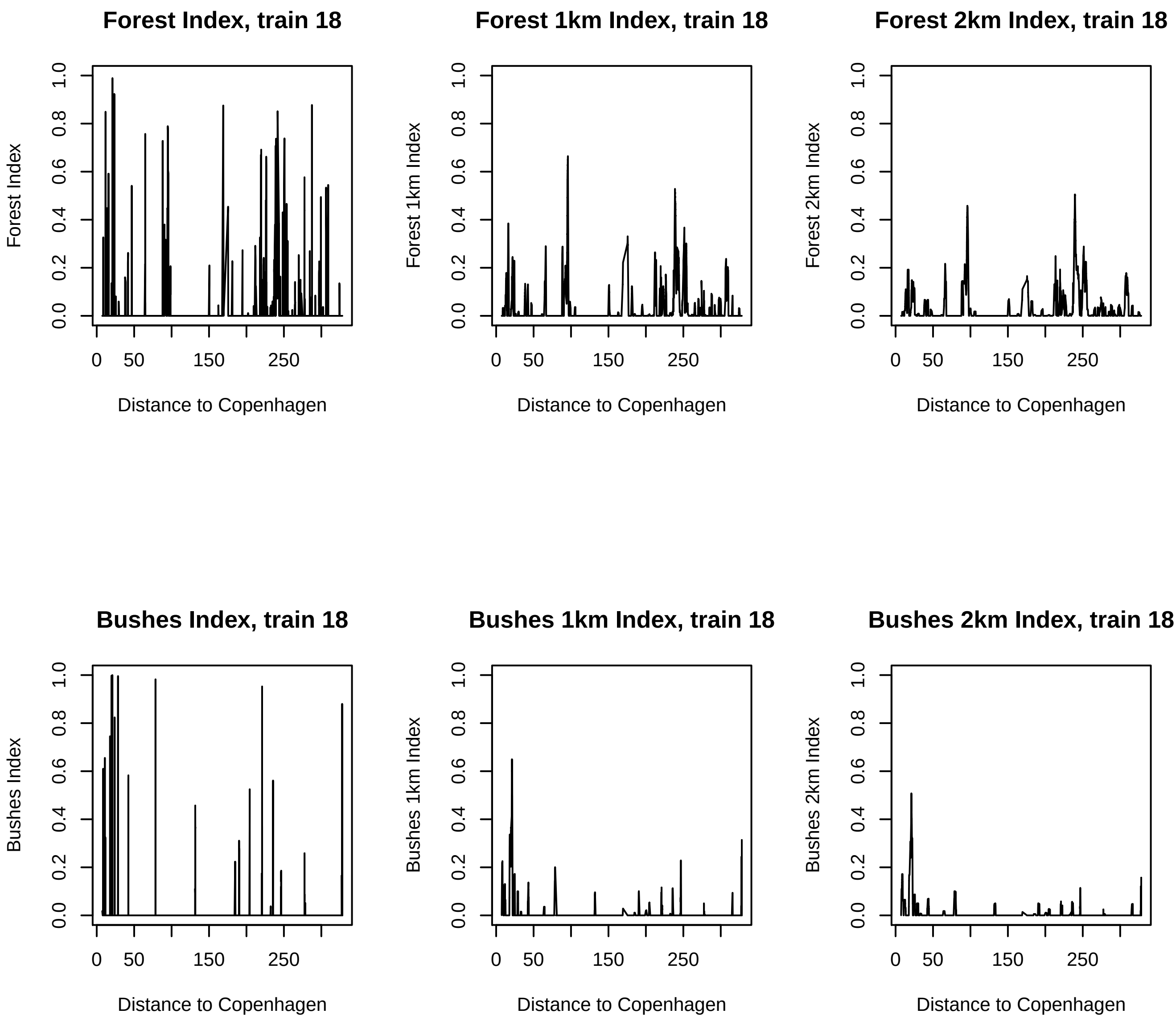

Forest 2km Index, train 17
Forest 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

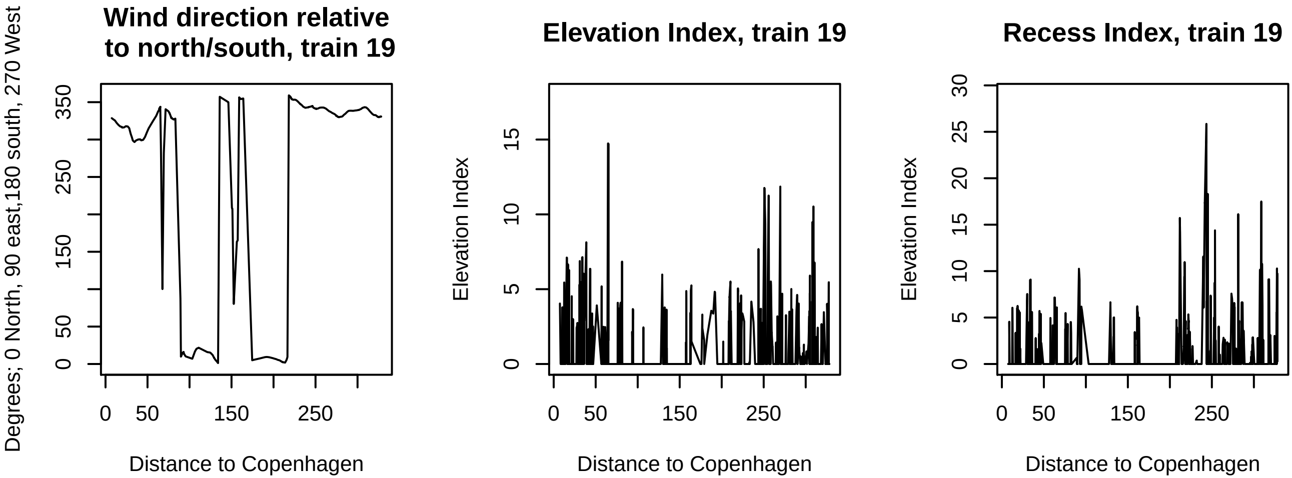

Bushes Index, train 17
Bushes Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

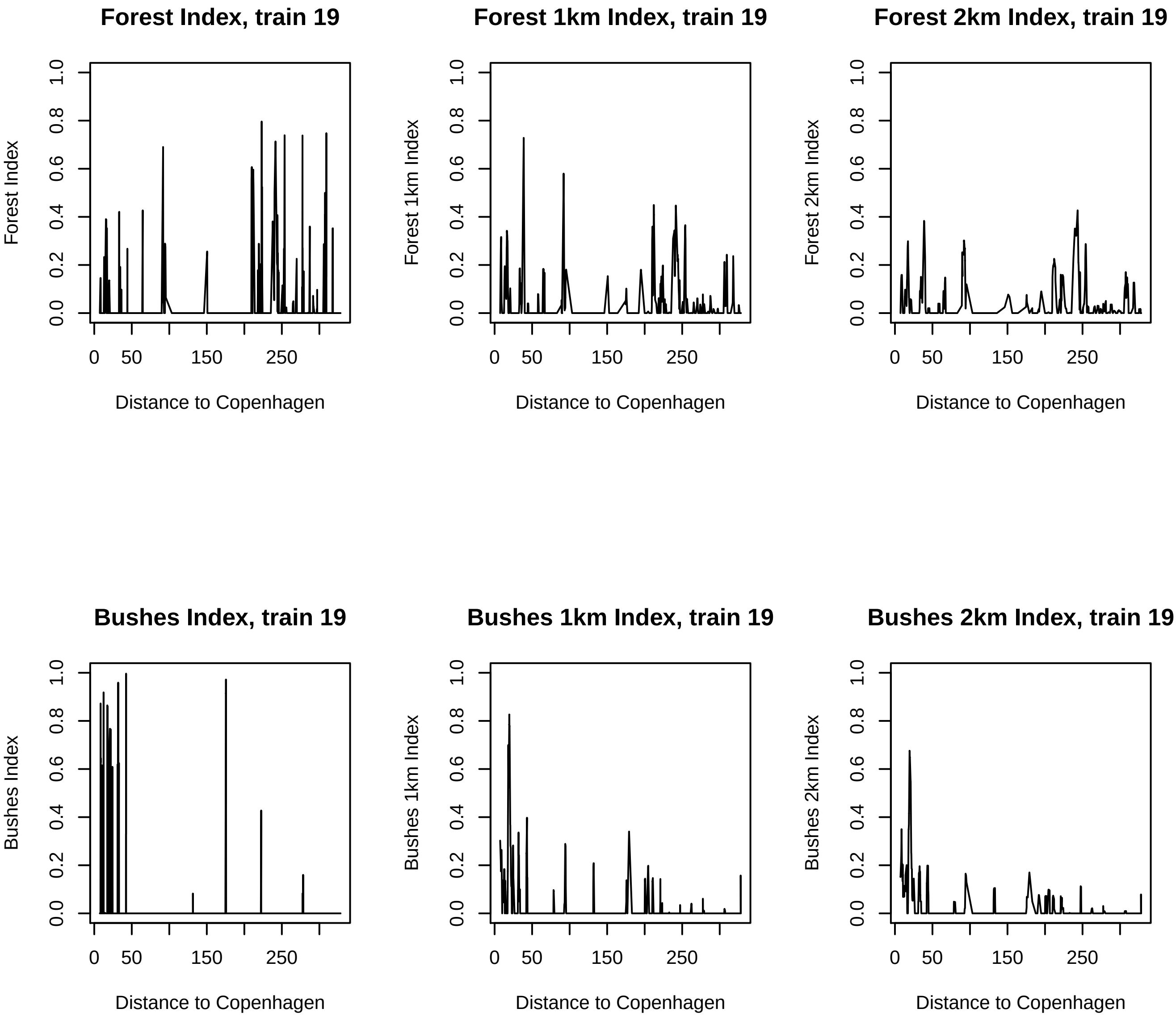

Bushes 1km Index, train 17
Bushes 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

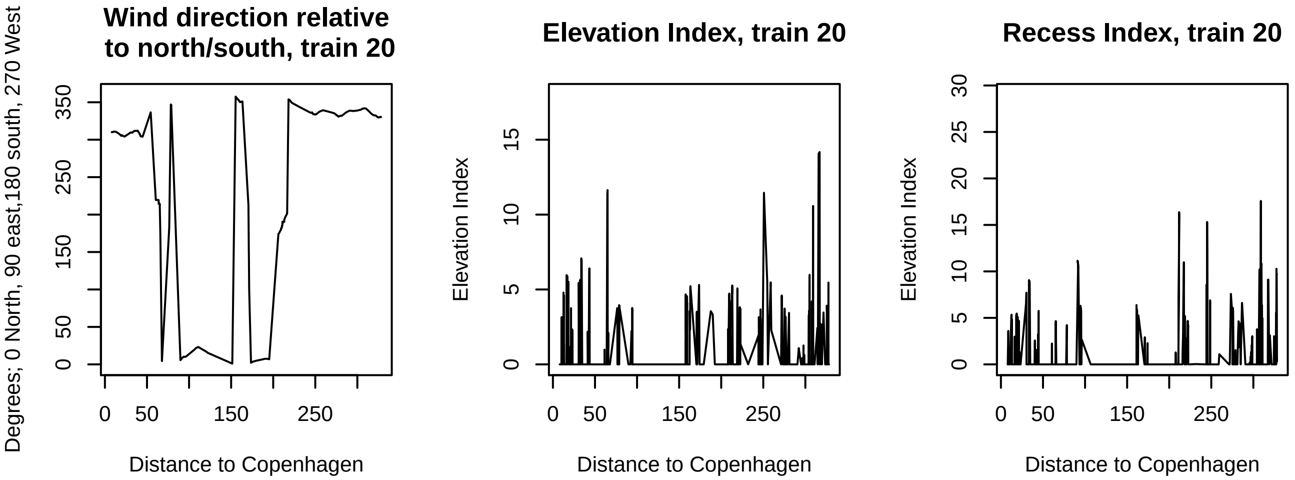

Bushes 2km Index, train 17
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

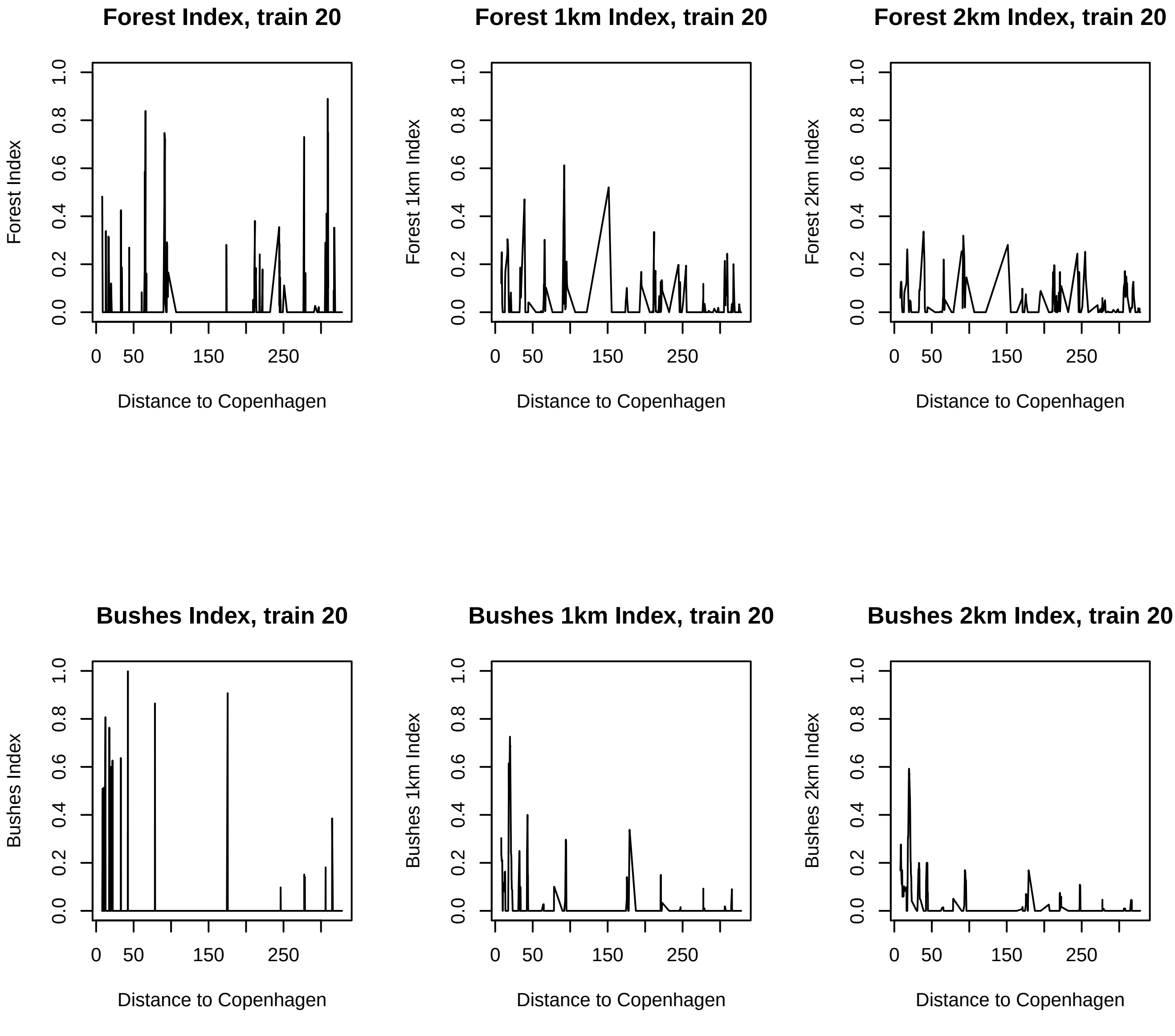

Wind direction relative to north/south, train 18
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 18
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 18
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

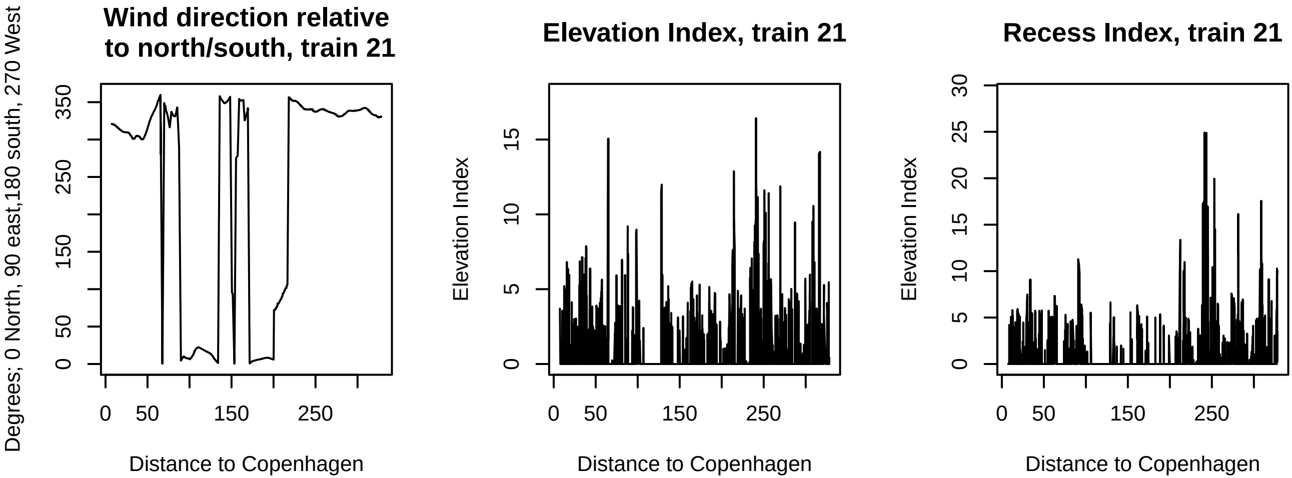

Forest Index, train 18
Forest Index
Distance to Copenhagen
Forest 1km Index, train 18
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 18
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 18
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 18
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 18
Bushes 2km Index
Distance to Copenhagen

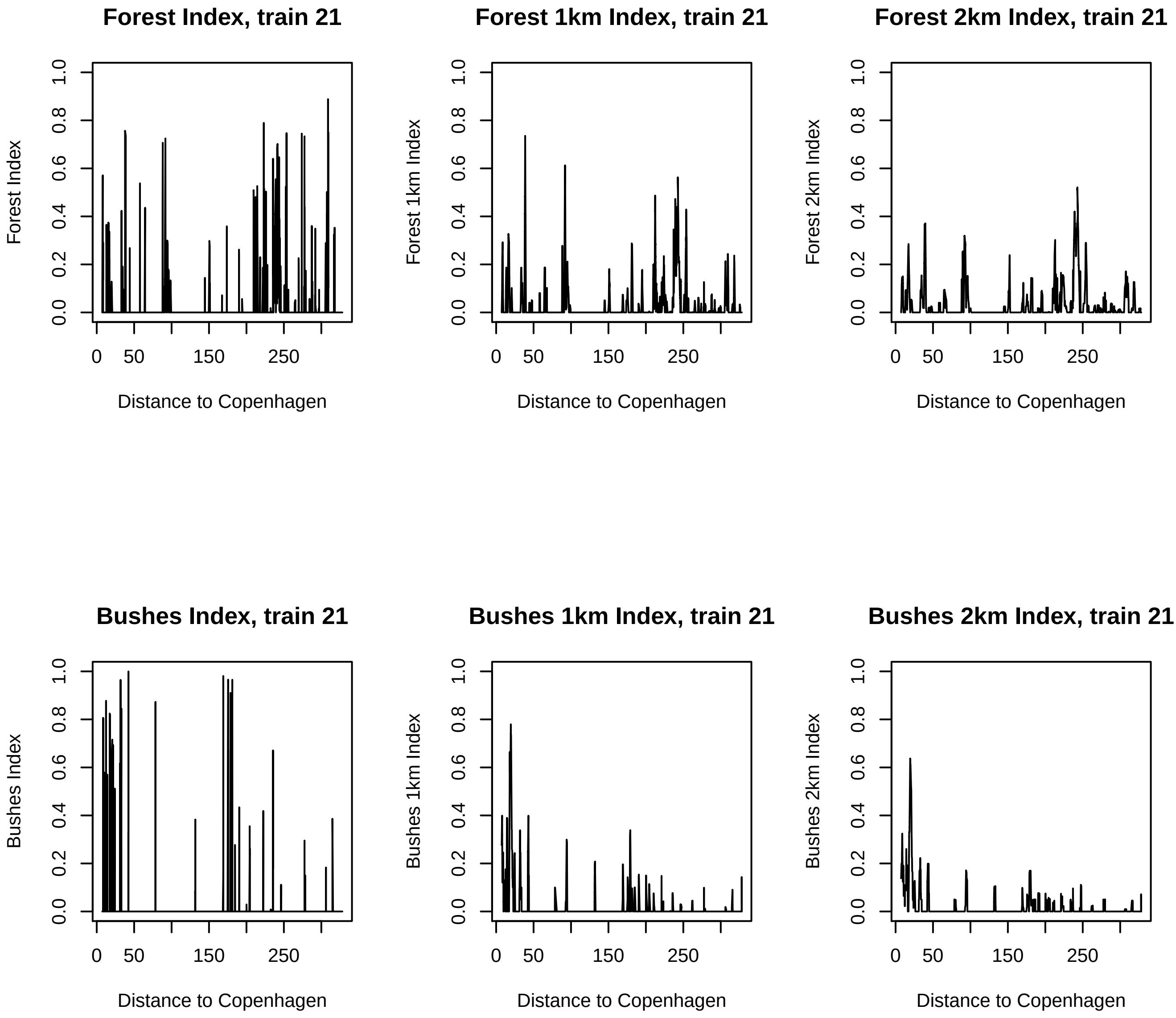

Wind direction relative to north/south, train 19
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
0
50
150
250
Distance to Copenhagen
Elevation Index, train 19
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 19
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

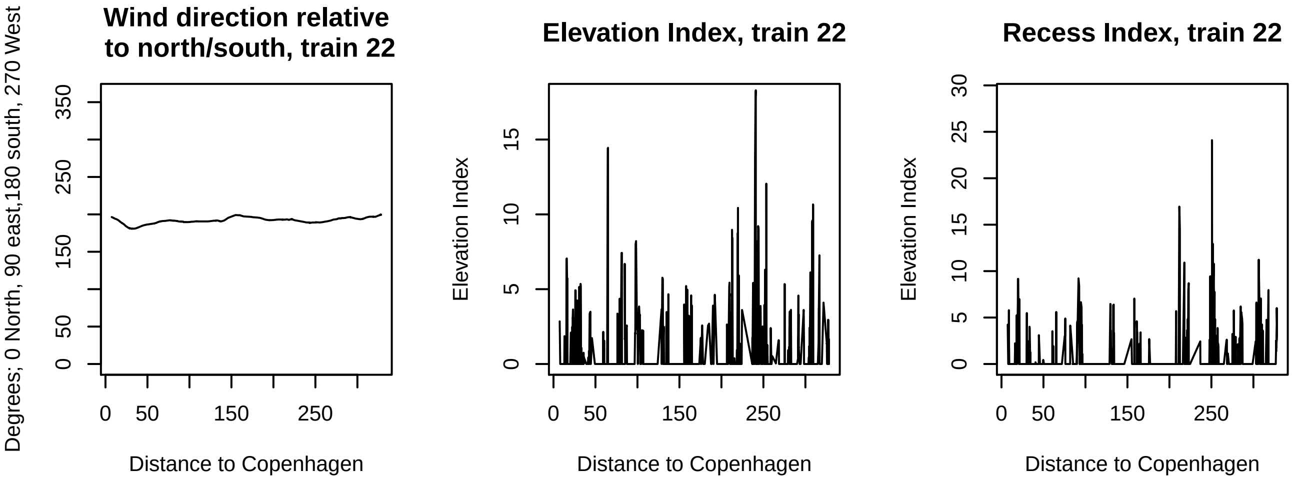

Forest Index, train 19
Forest Index
Distance to Copenhagen
Forest 1km Index, train 19
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 19
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 19
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 19
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 19
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

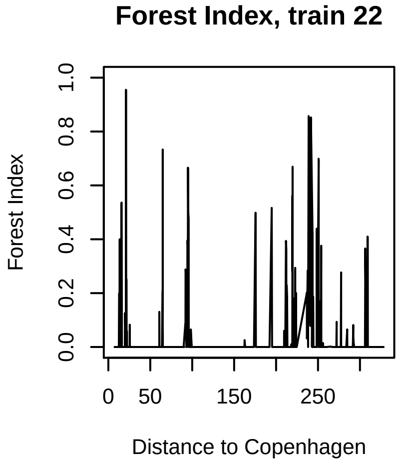

Wind direction relative to north/south, train 20
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 20
Elevation Index
5
10
15
Recess Index, train 20
20
25
30

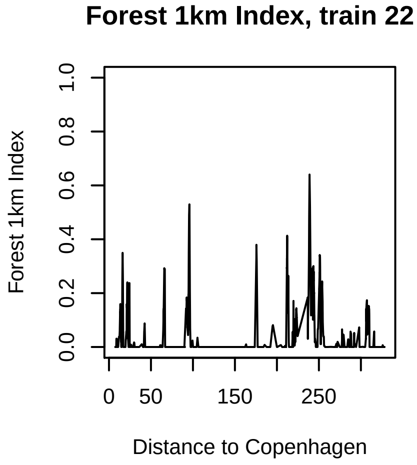

Forest Index, train 20
Forest Index
Distance to Copenhagen
Forest 1km Index, train 20
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 20
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 20
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 20
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 20
Bushes 2km Index
Distance to Copenhagen

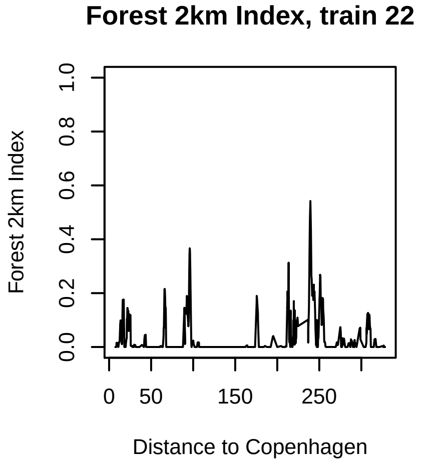

Wind direction relative to north/south, train 21
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 21
Elevation Index
0
5
10
15
Distance to Copenhagen
Recess Index, train 21
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen

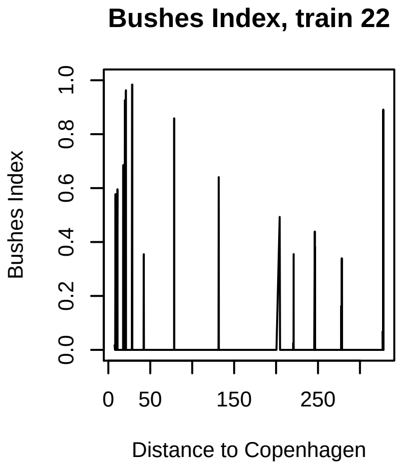

Forest Index, train 21
Forest Index
Distance to Copenhagen
Forest 1km Index, train 21
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 21
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 21
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 21
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 21
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

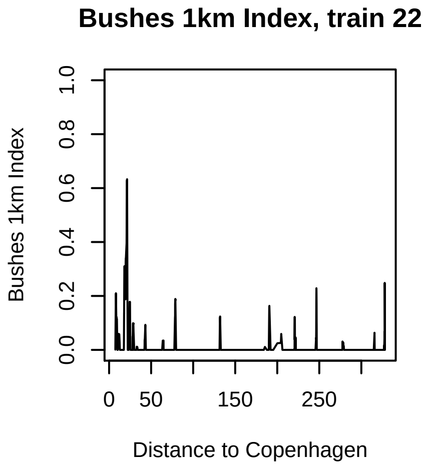

Wind direction relative to north/south, train 22
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
0
50
150
250
Distance to Copenhagen
Elevation Index, train 22
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 22
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

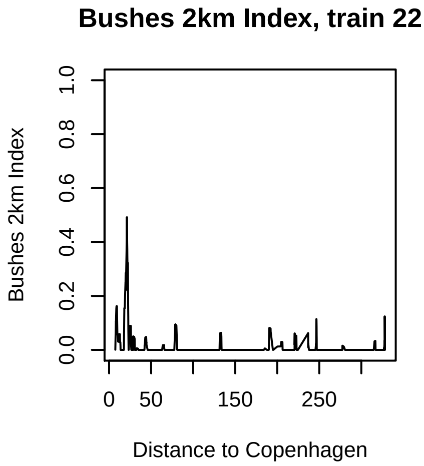

Forest Index, train 22
Forest Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

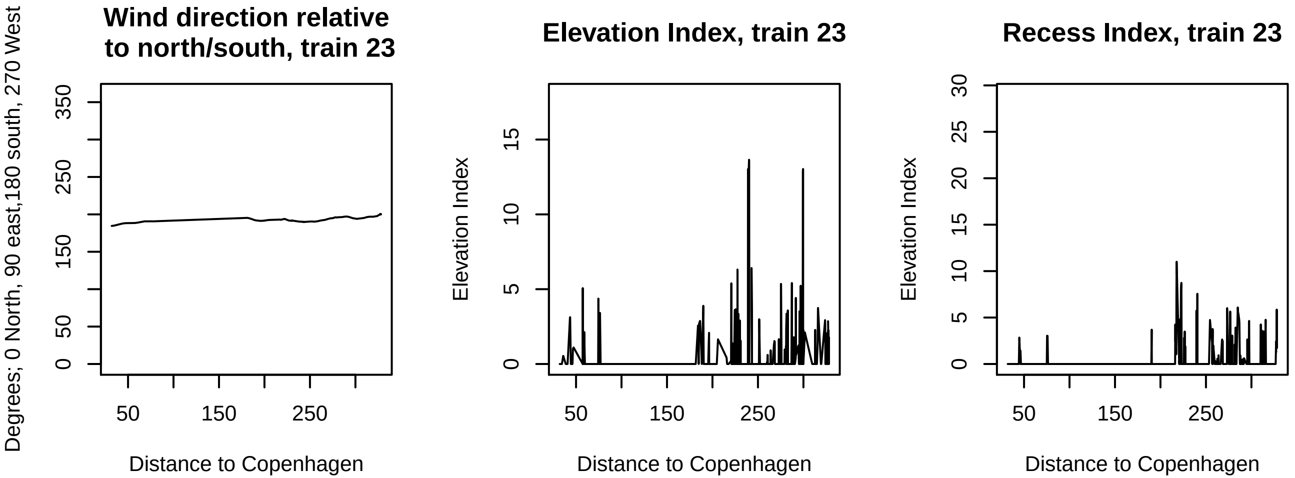

Forest 1km Index, train 22
Forest 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

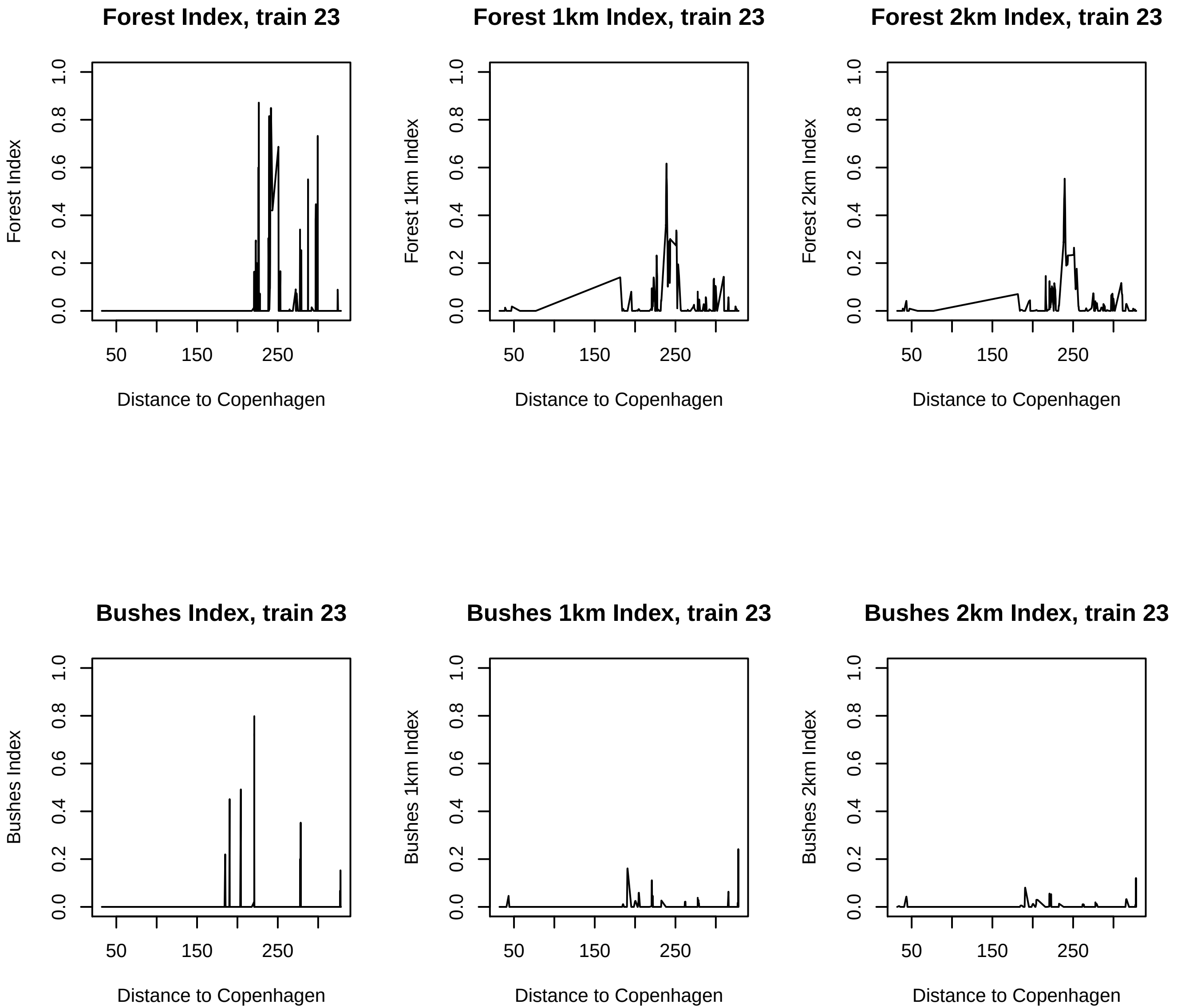

Forest 2km Index, train 22
Forest 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

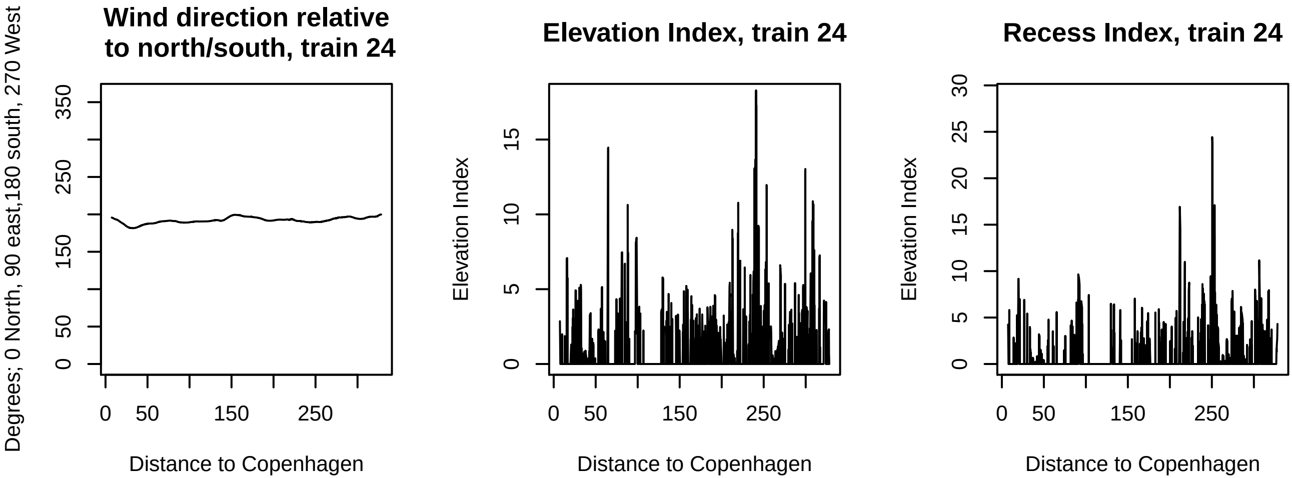

Bushes Index, train 22
Bushes Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

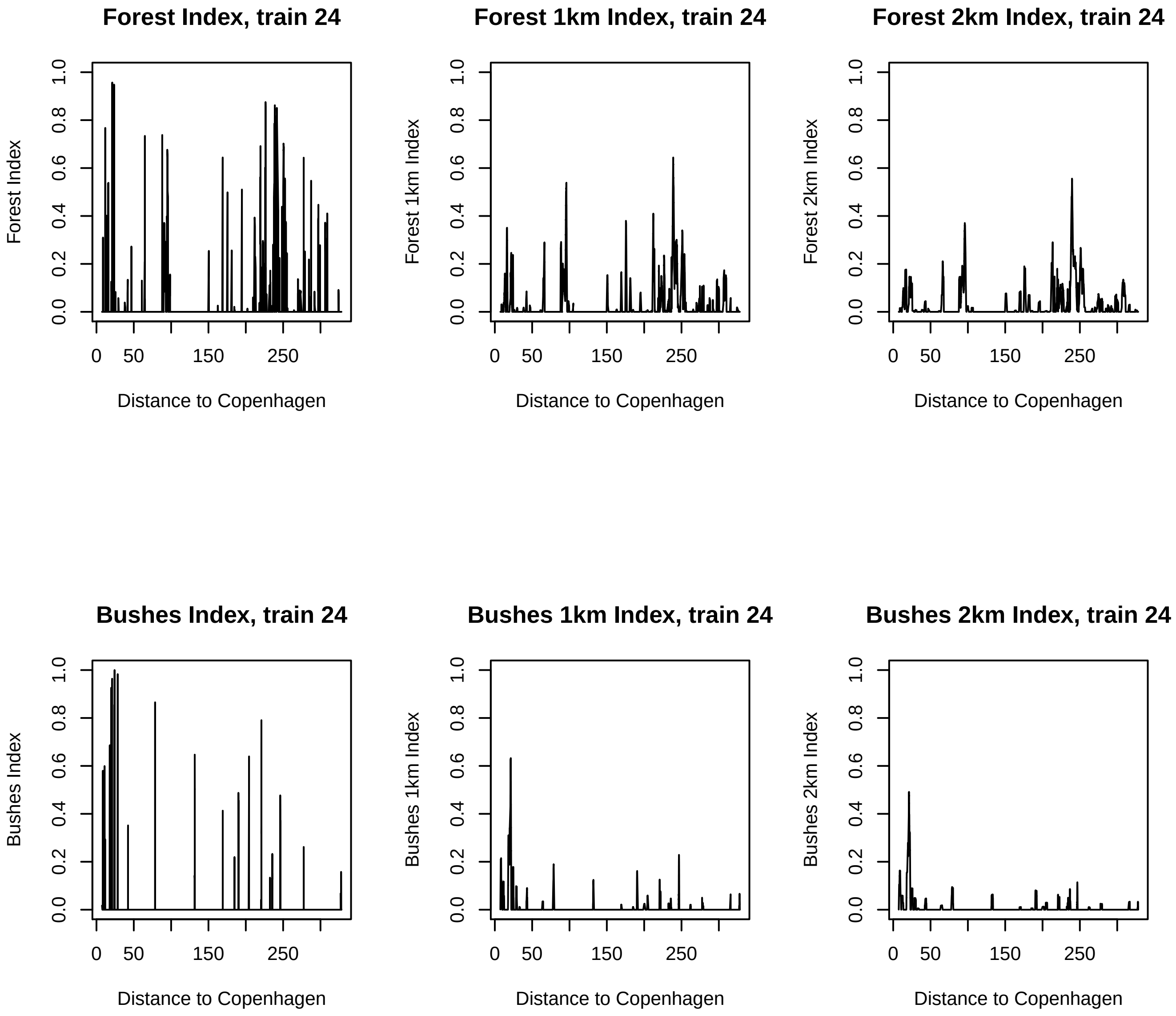

Bushes 1km Index, train 22
Bushes 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

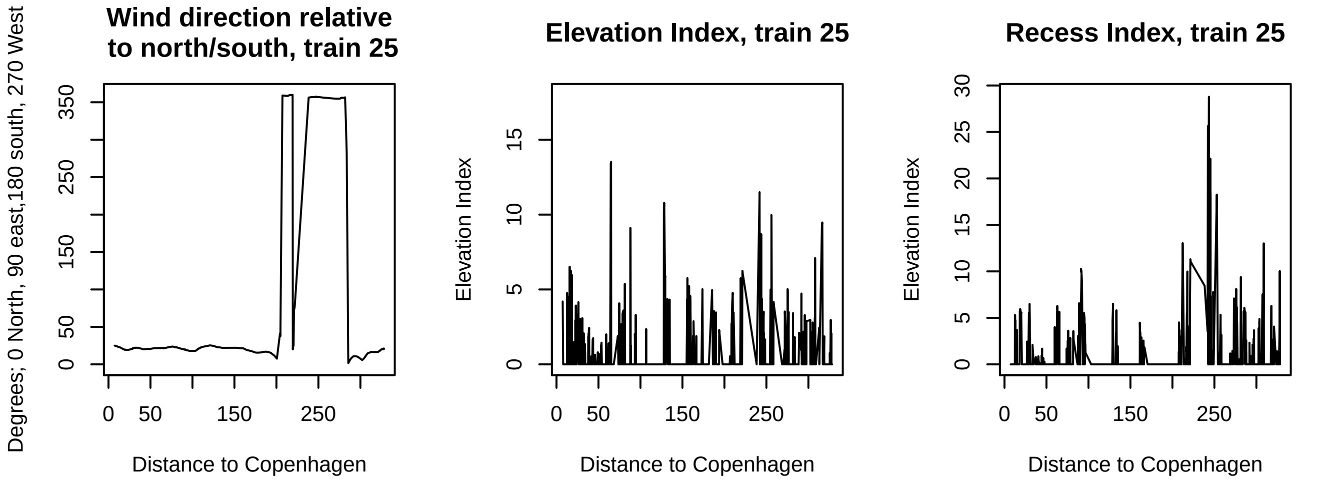

Bushes 2km Index, train 22
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

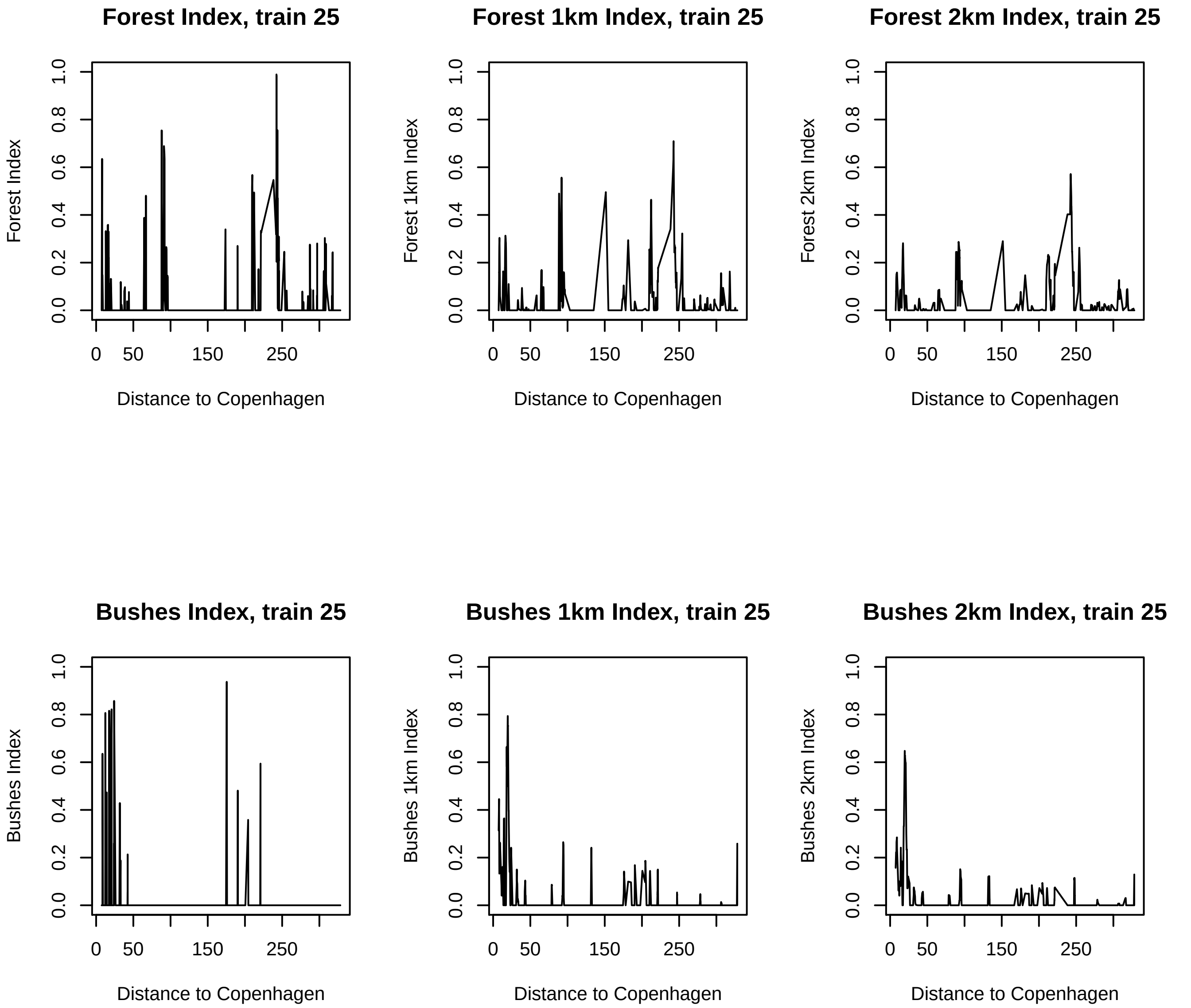

Wind direction relative to north/south, train 23
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
50
150
250
Distance to Copenhagen
Elevation Index, train 23
Elevation Index
0
5
10
15
50
150
250
Distance to Copenhagen
Recess Index, train 23
Elevation Index
0
5
10
15
20
25
30
50
150
250
Distance to Copenhagen

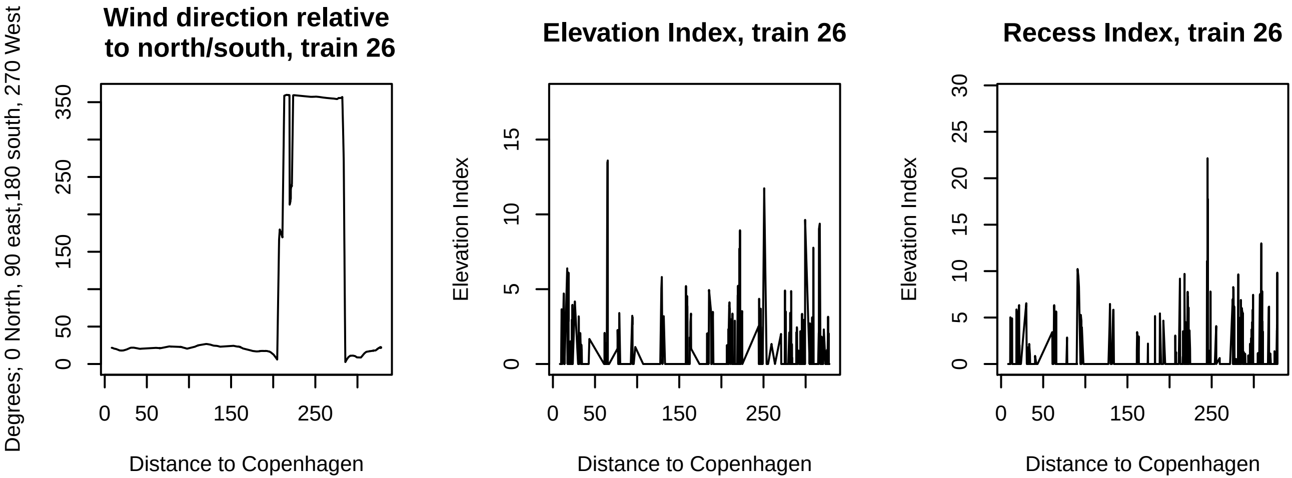

Forest Index, train 23
Forest Index
Forest 1km Index, train 23
Forest 1km Index
Forest 2km Index, train 23
Forest 2km Index
Bushes Index, train 23
Bushes Index
Bushes 1km Index, train 23
Bushes 1km Index
Bushes 2km Index, train 23
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
50
150
250
Distance to Copenhagen

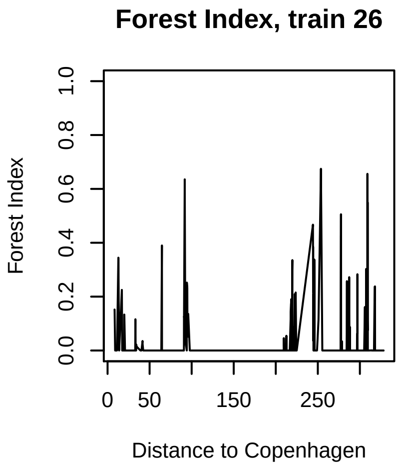

Wind direction relative to north/south, train 24
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
0
50
150
250
Elevation Index, train 24
Elevation Index
0
5
10
15
Distance to Copenhagen
0
50
150
250
Recess Index, train 24
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250

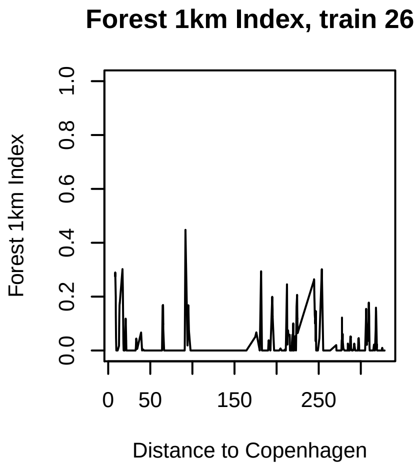

Forest Index, train 24
Forest Index
Distance to Copenhagen
Forest 1km Index, train 24
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 24
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 24
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 24
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 24
Bushes 2km Index
Distance to Copenhagen

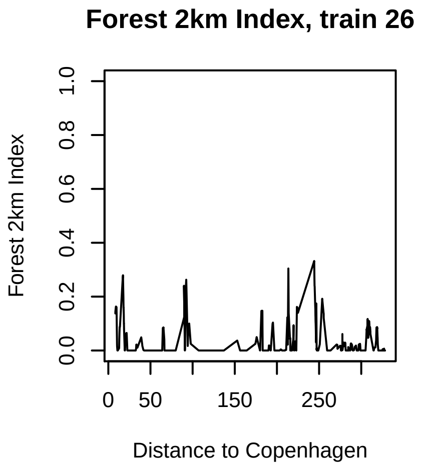

Wind direction relative to north/south, train 25
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 25
Elevation Index
0
5
10
15
Distance to Copenhagen
Recess Index, train 25
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

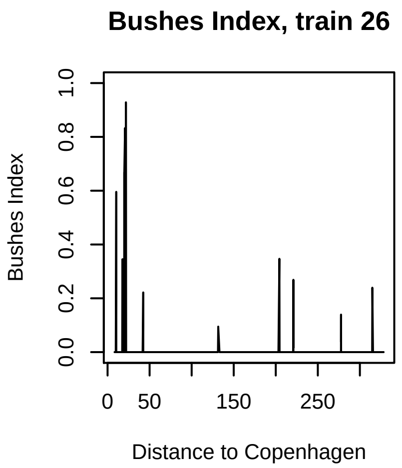

Forest Index, train 25
Forest 1km Index, train 25
Forest 2km Index, train 25
Forest Index
Forest 1km Index
Forest 2km Index
Bushes Index, train 25
Bushes 1km Index, train 25
Bushes 2km Index, train 25
Bushes Index
Bushes 1km Index
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

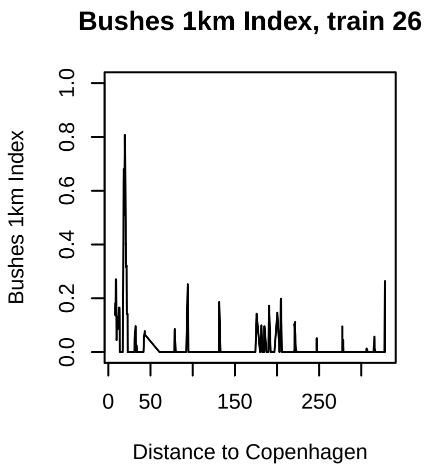

Wind direction relative to north/south, train 26
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
Elevation Index, train 26
Elevation Index
0
5
10
15
Distance to Copenhagen
Recess Index, train 26
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen

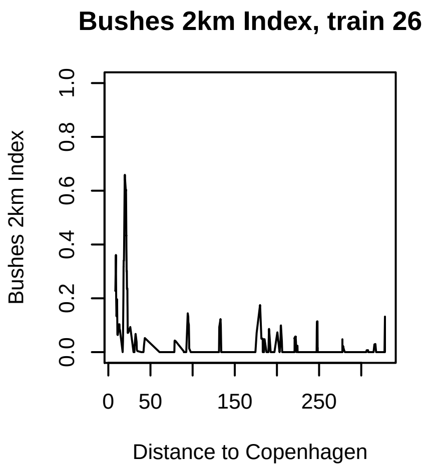

Forest Index, train 26
Forest Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

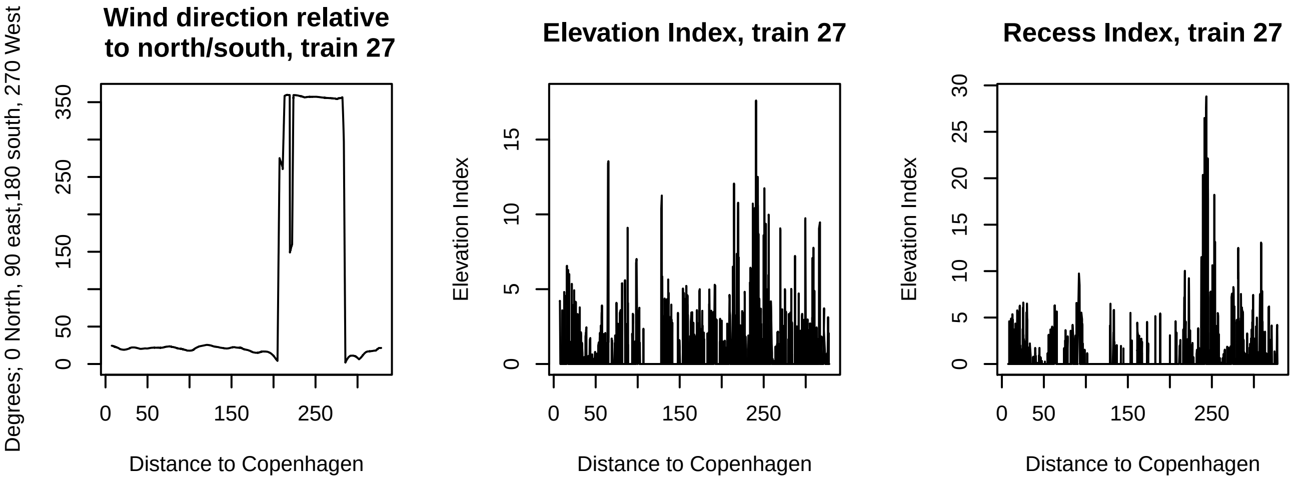

Forest 1km Index, train 26
Forest 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen


Forest 2km Index, train 26
Forest 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

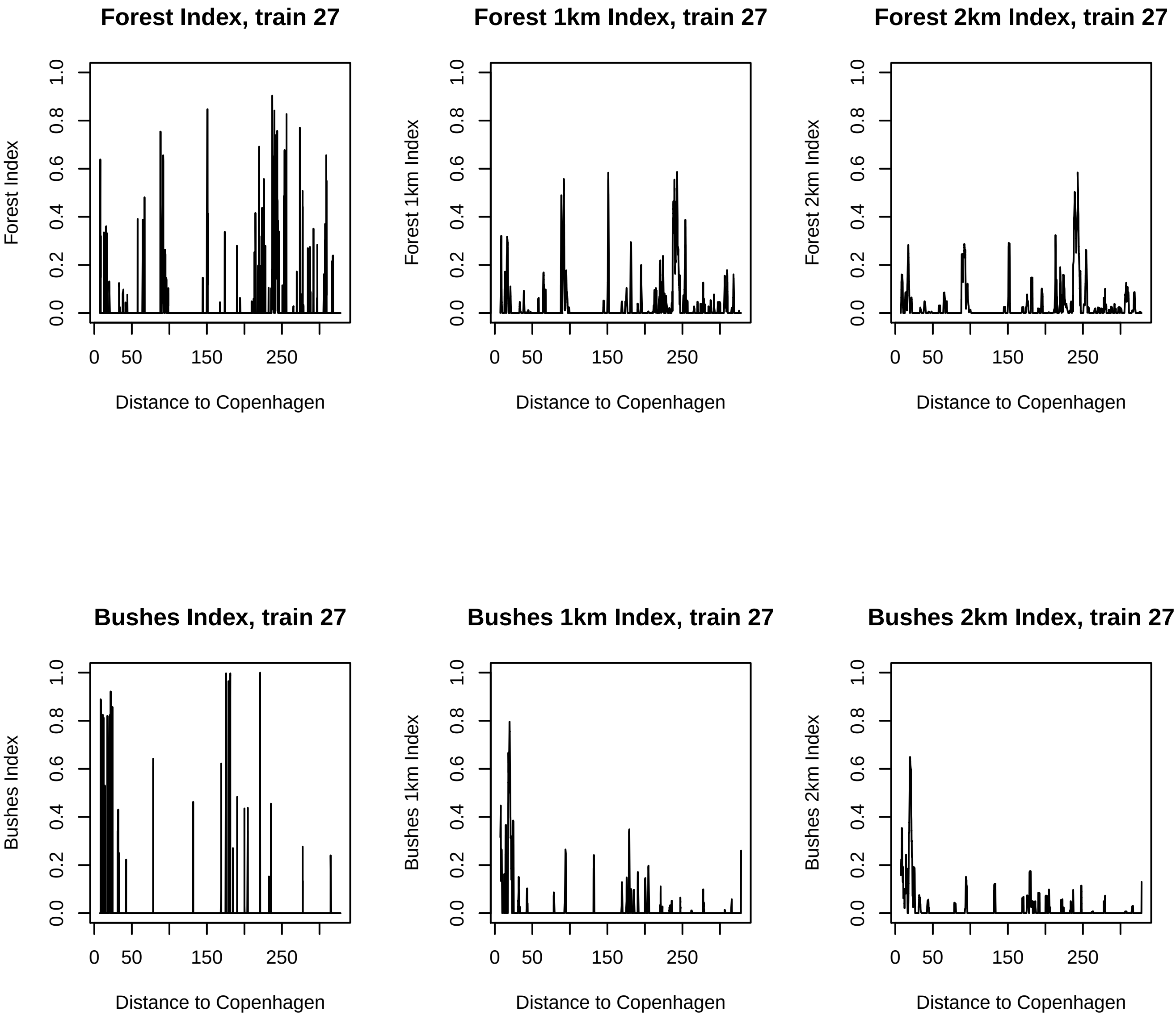

Bushes Index, train 26
Bushes Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

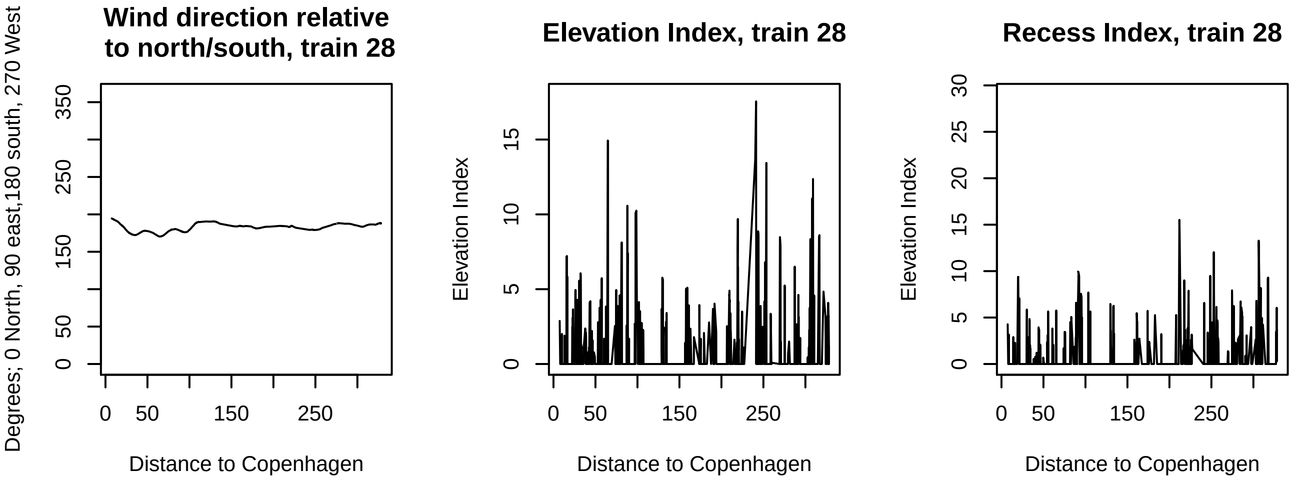

Bushes 1km Index, train 26
Bushes 1km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

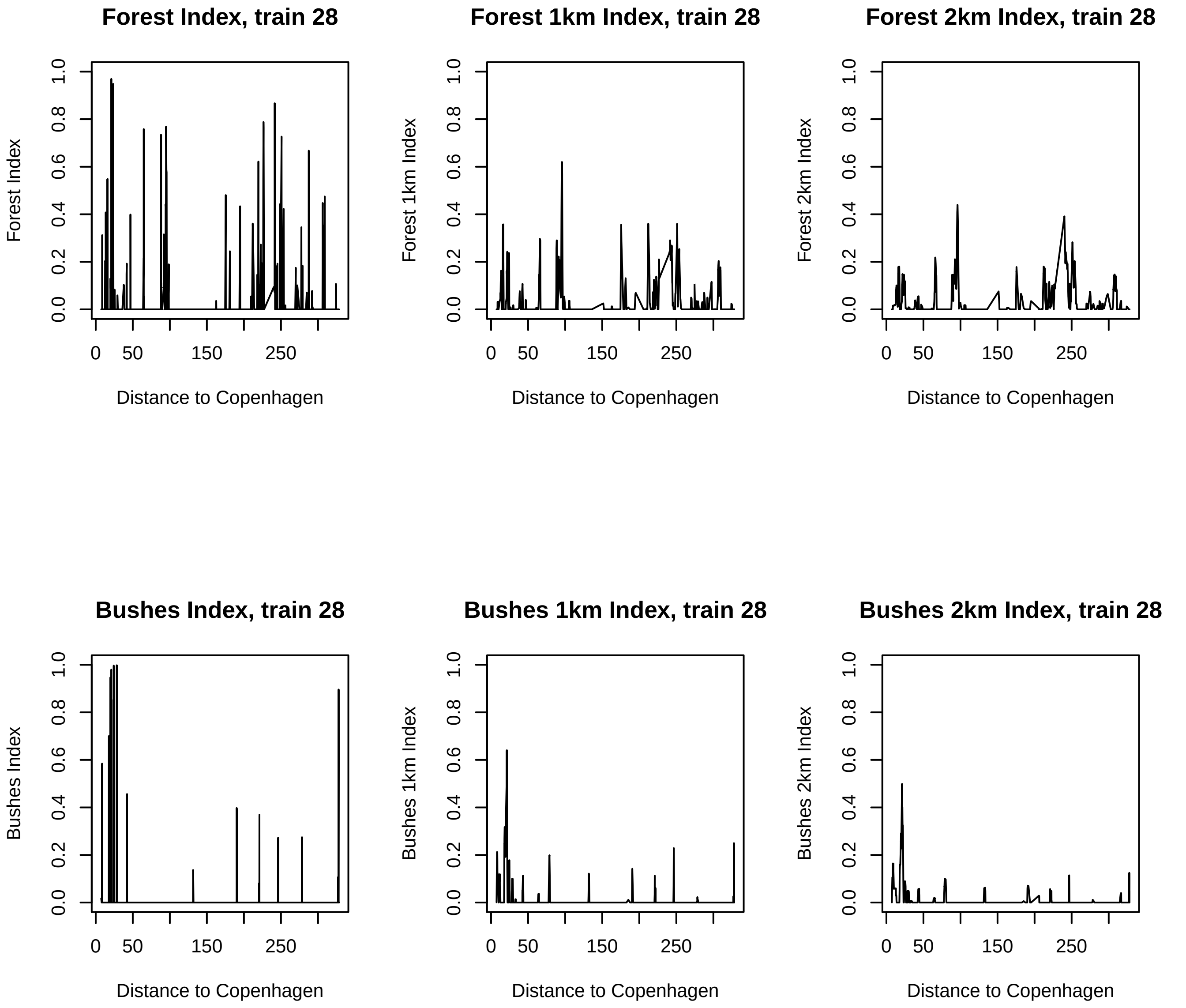

Bushes 2km Index, train 26
Bushes 2km Index
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250
Distance to Copenhagen

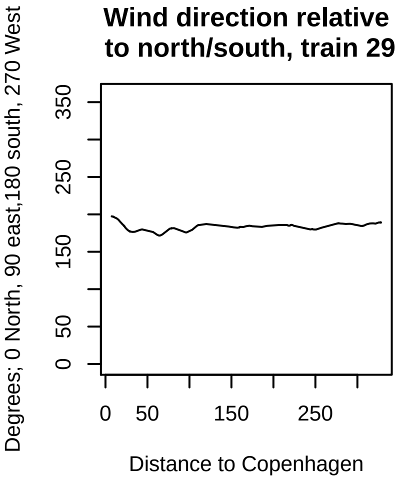


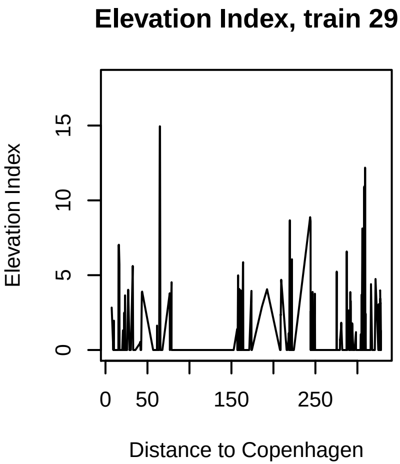
Wind direction relative to north/south, train 27
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen
0
50
150
250
Elevation Index, train 27
Elevation Index
0
5
10
15
Distance to Copenhagen
0
50
150
250
Recess Index, train 27
Elevation Index
0
5
10
15
20
25
30
Distance to Copenhagen
0
50
150
250

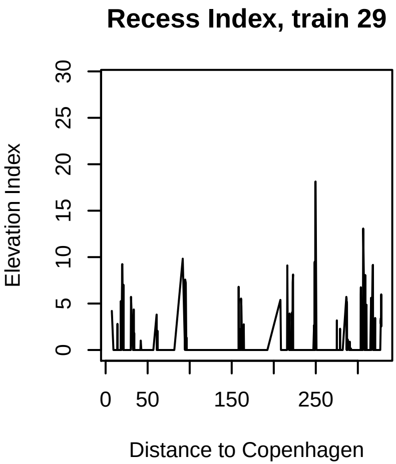

Forest Index, train 27
Forest Index
Distance to Copenhagen
Forest 1km Index, train 27
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 27
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 27
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 27
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 27
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

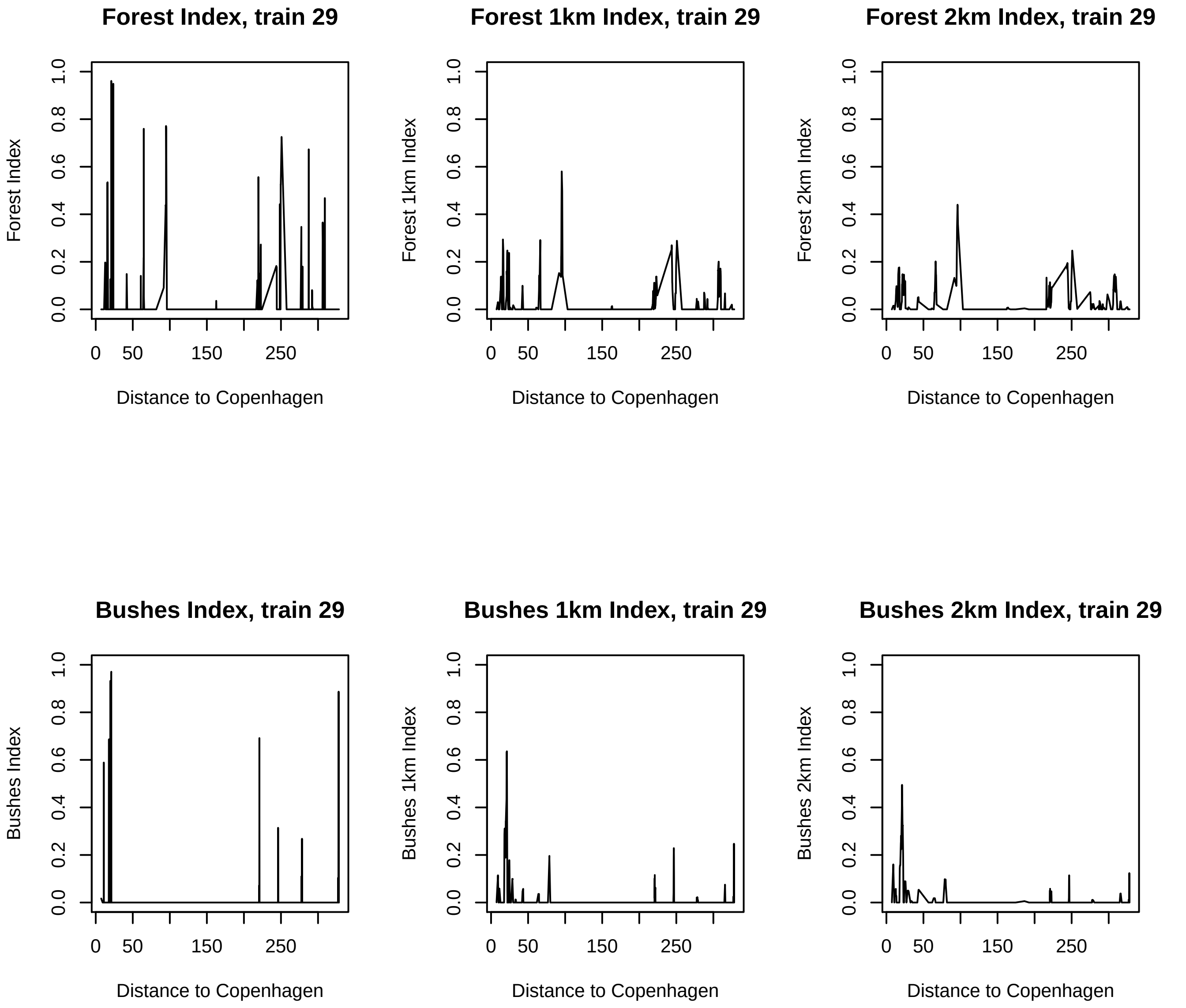

Wind direction relative to north/south, train 28
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
0
50
150
250
Distance to Copenhagen
Elevation Index, train 28
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen
Recess Index, train 28
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

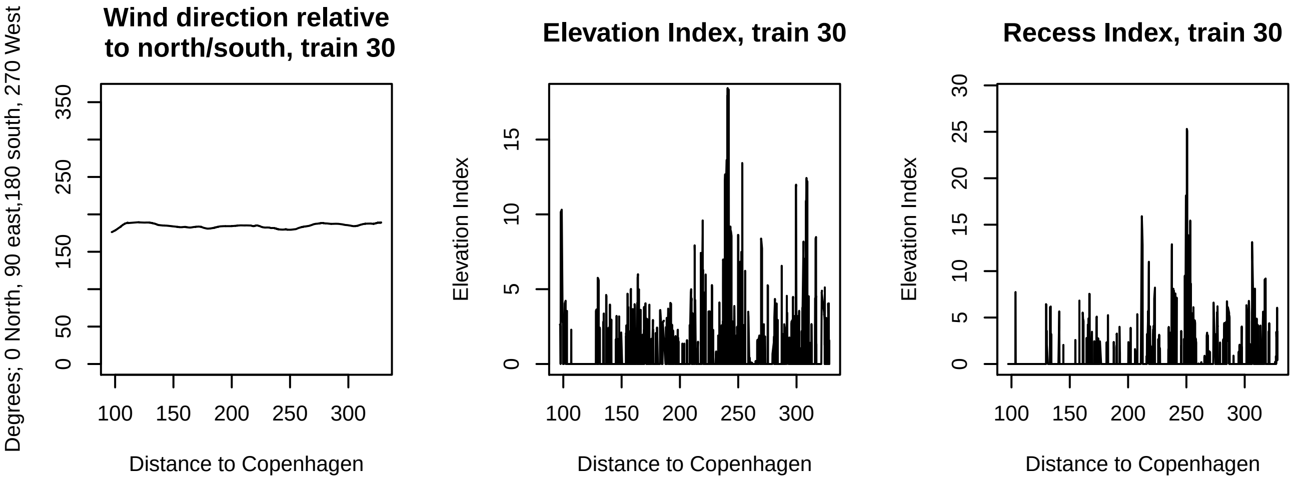

Forest Index, train 28
Forest Index
Distance to Copenhagen
Forest 1km Index, train 28
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 28
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 28
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 28
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 28
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250

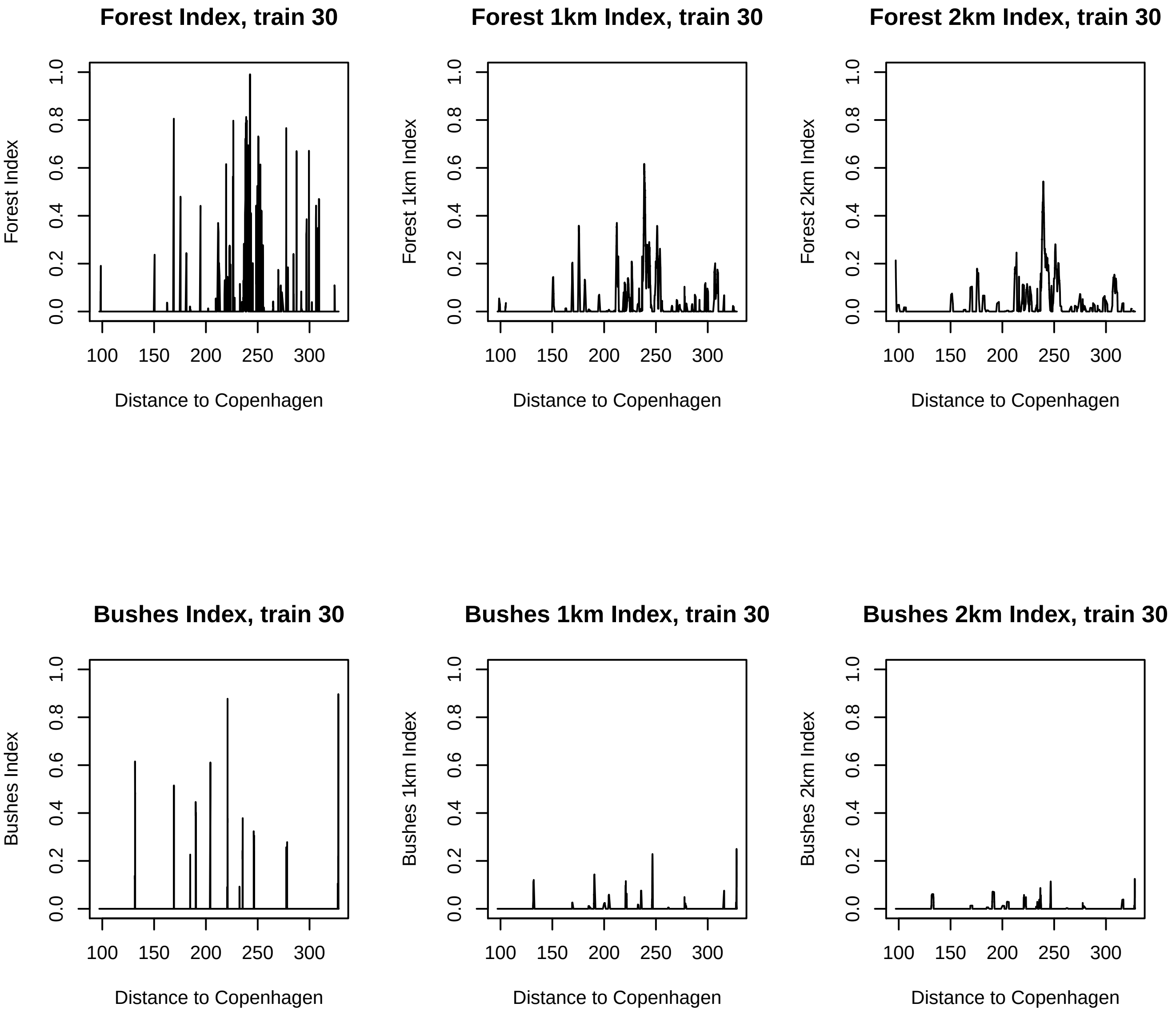

Wind direction relative to north/south, train 29
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
Distance to Copenhagen


Elevation Index, train 29
Elevation Index
0
5
10
15
0
50
150
250
Distance to Copenhagen

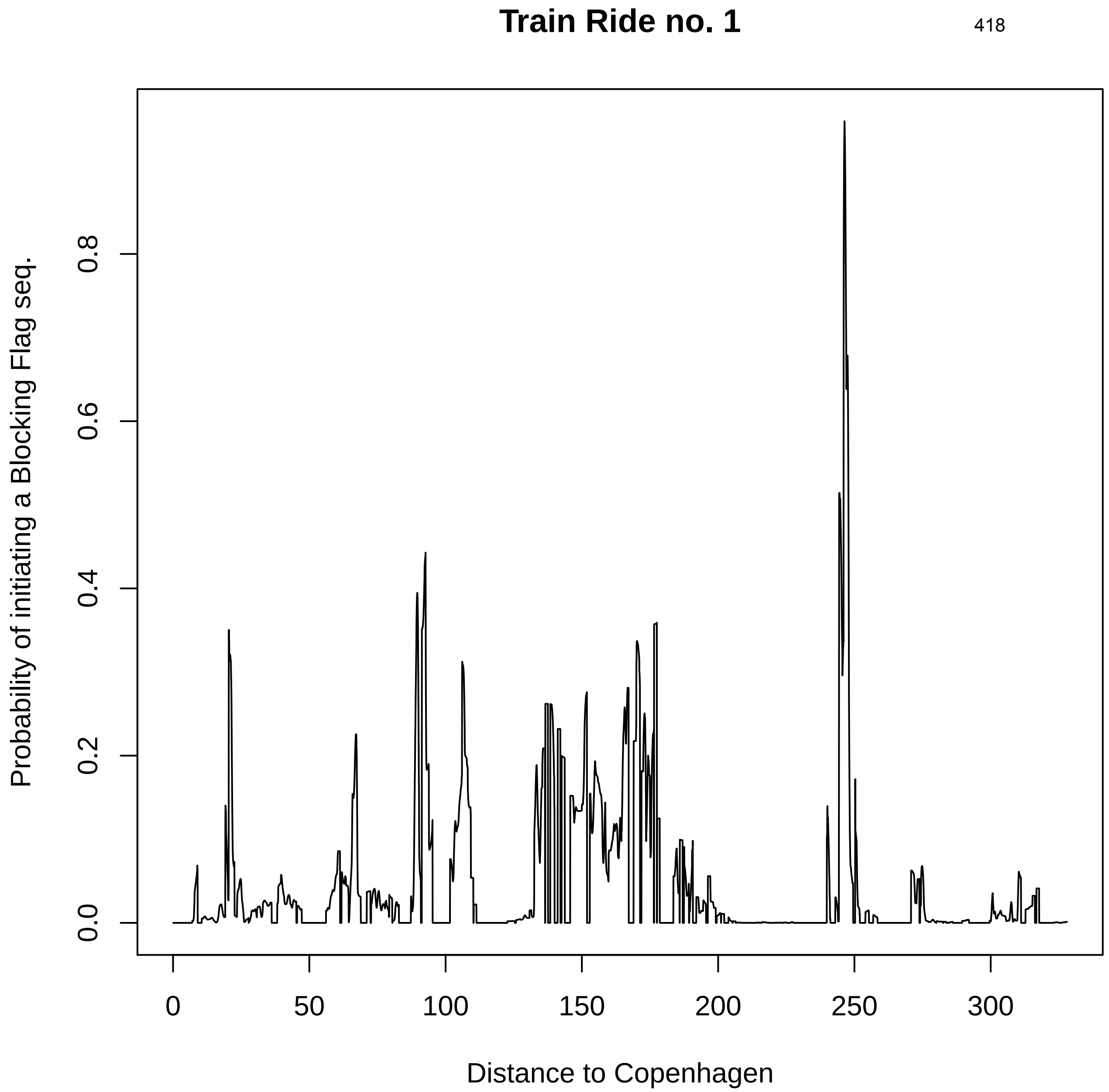

Recess Index, train 29
Elevation Index
0
5
10
15
20
25
30
0
50
150
250
Distance to Copenhagen

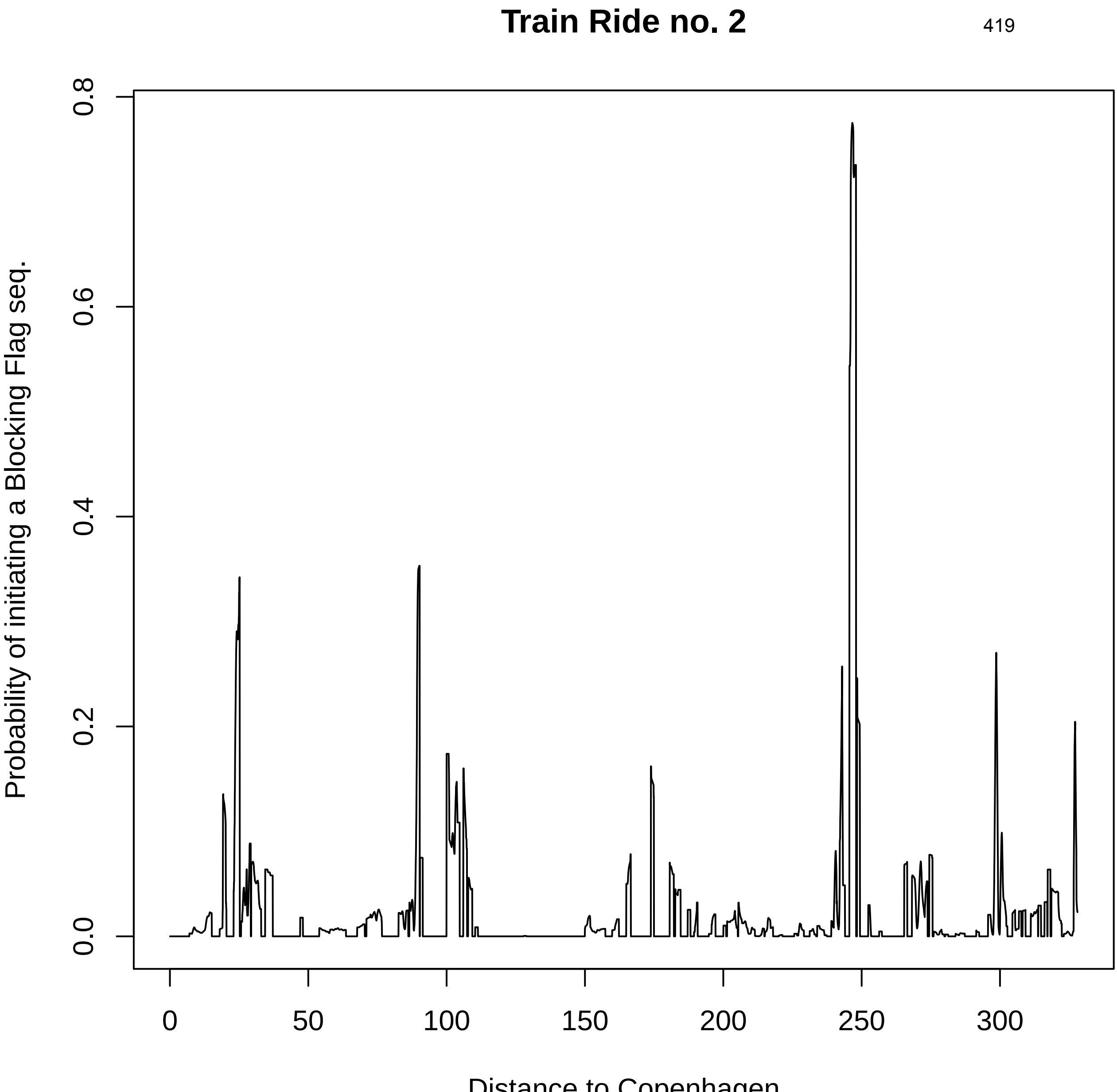

Forest Index, train 29
Forest Index
Distance to Copenhagen
Forest 1km Index, train 29
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 29
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 29
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 29
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 29
Bushes 2km Index
Distance to Copenhagen
0.0
0.2
0.4
0.6
0.8
1.0
0
50
150
250


Wind direction relative to north/south, train 30
Degrees; 0 North, 90 east,180 south, 270 West
0
50
150
250
350
100
150
200
250
300
Distance to Copenhagen
Elevation Index, train 30
Elevation Index
0
5
10
15
100
150
200
250
300
Distance to Copenhagen
Recess Index, train 30
Elevation Index
0
5
10
15
20
25
30
100
150
200
250
300
Distance to Copenhagen

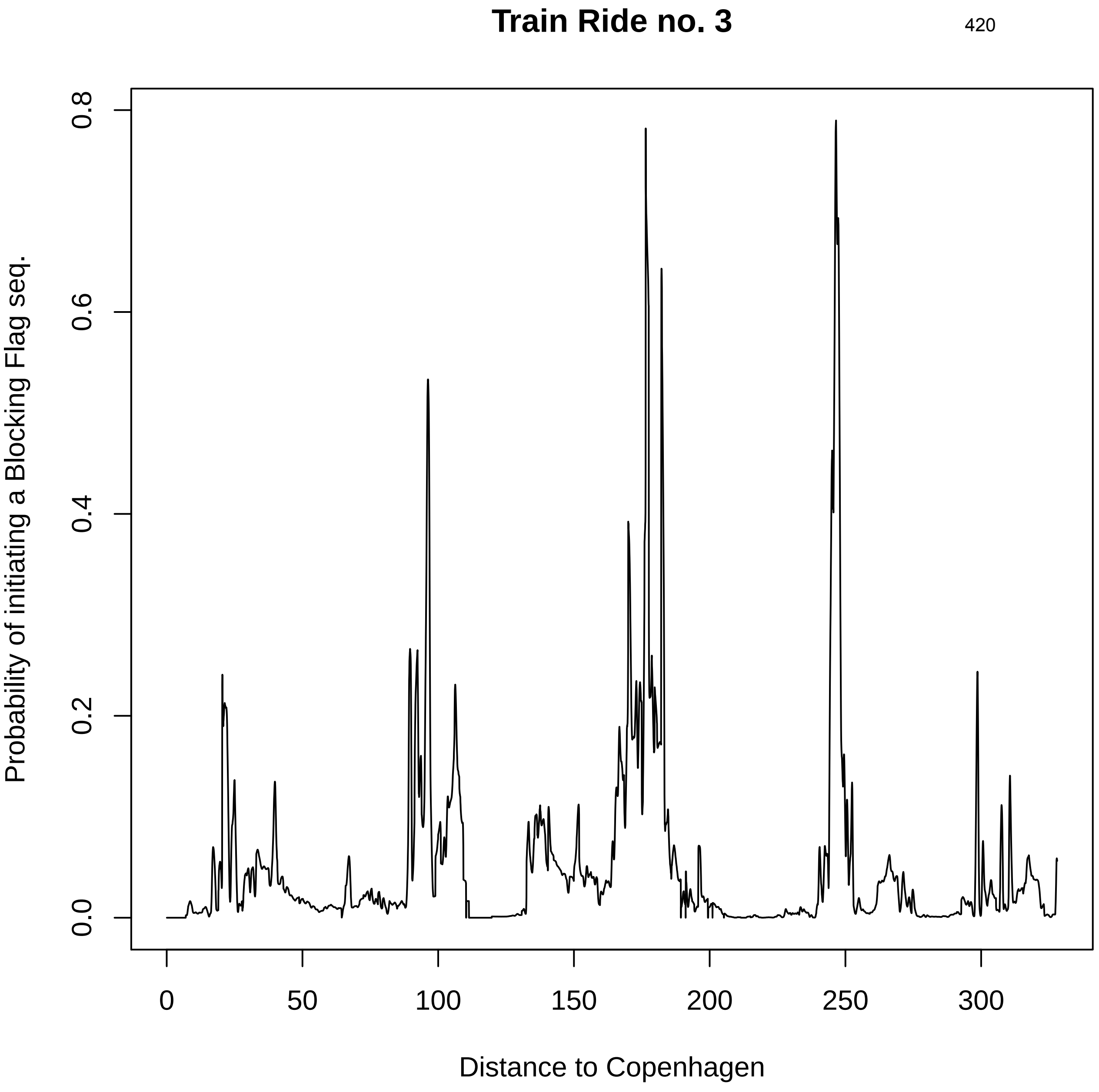

Forest Index, train 30
Forest Index
Distance to Copenhagen
Forest 1km Index, train 30
Forest 1km Index
Distance to Copenhagen
Forest 2km Index, train 30
Forest 2km Index
Distance to Copenhagen
Bushes Index, train 30
Bushes Index
Distance to Copenhagen
Bushes 1km Index, train 30
Bushes 1km Index
Distance to Copenhagen
Bushes 2km Index, train 30
Bushes 2km Index
Distance to Copenhagen

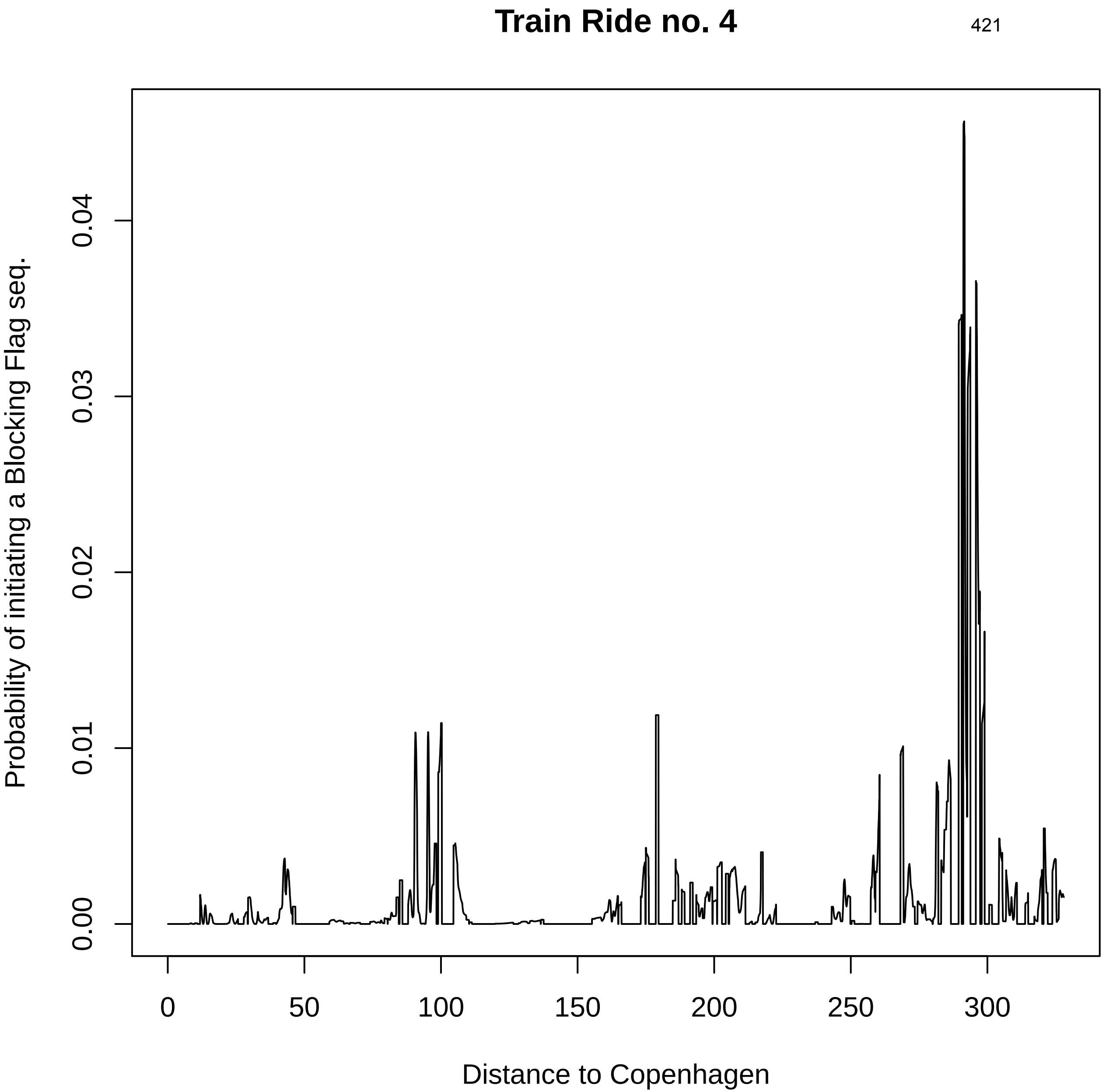
Annex I: The probability of initiating a Blocking Flag sequence at 180 km/h as a function of distance to Copenhagen Central Station, individual train rides and weighted together.


Train Ride no. 1
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

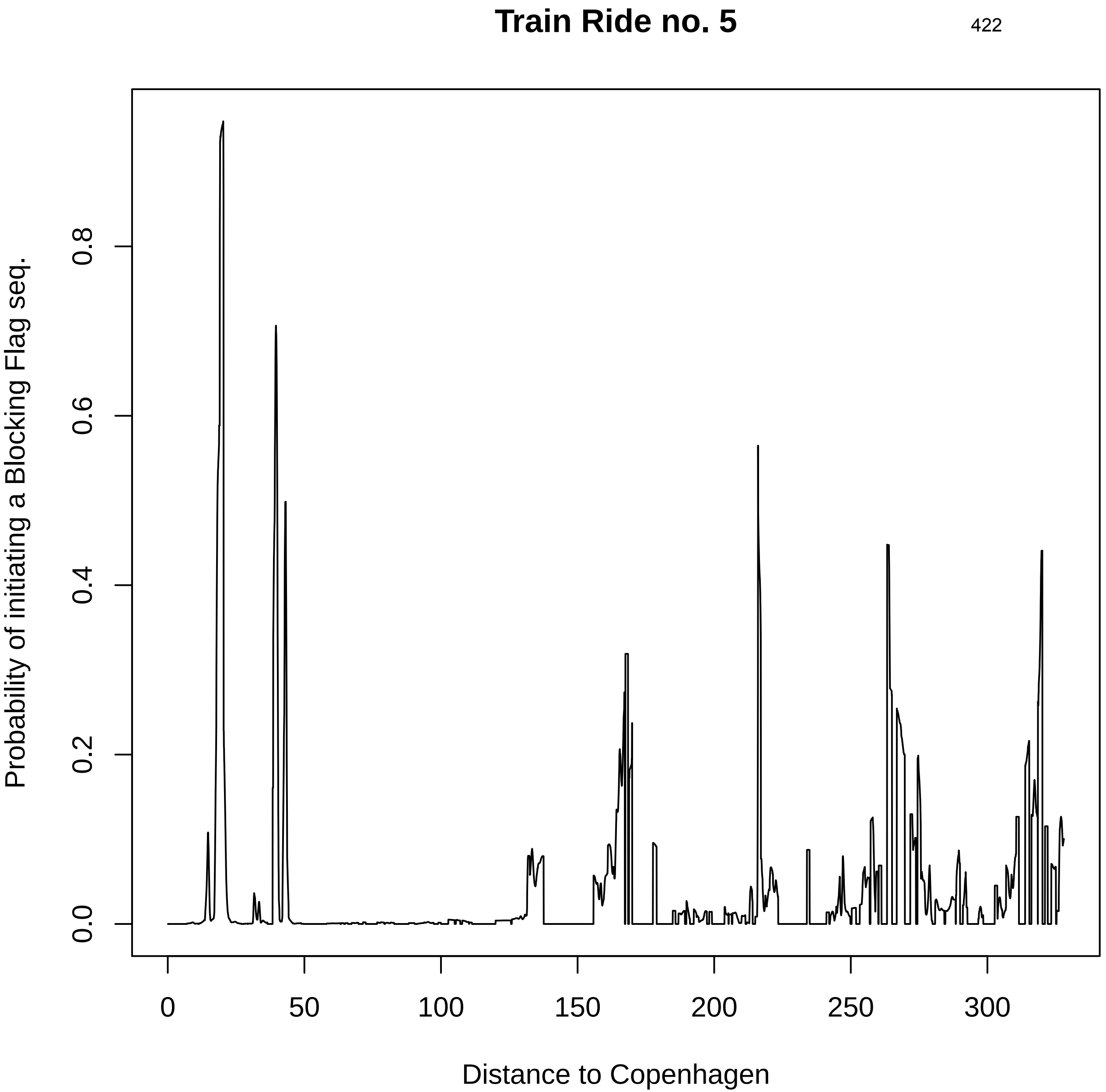


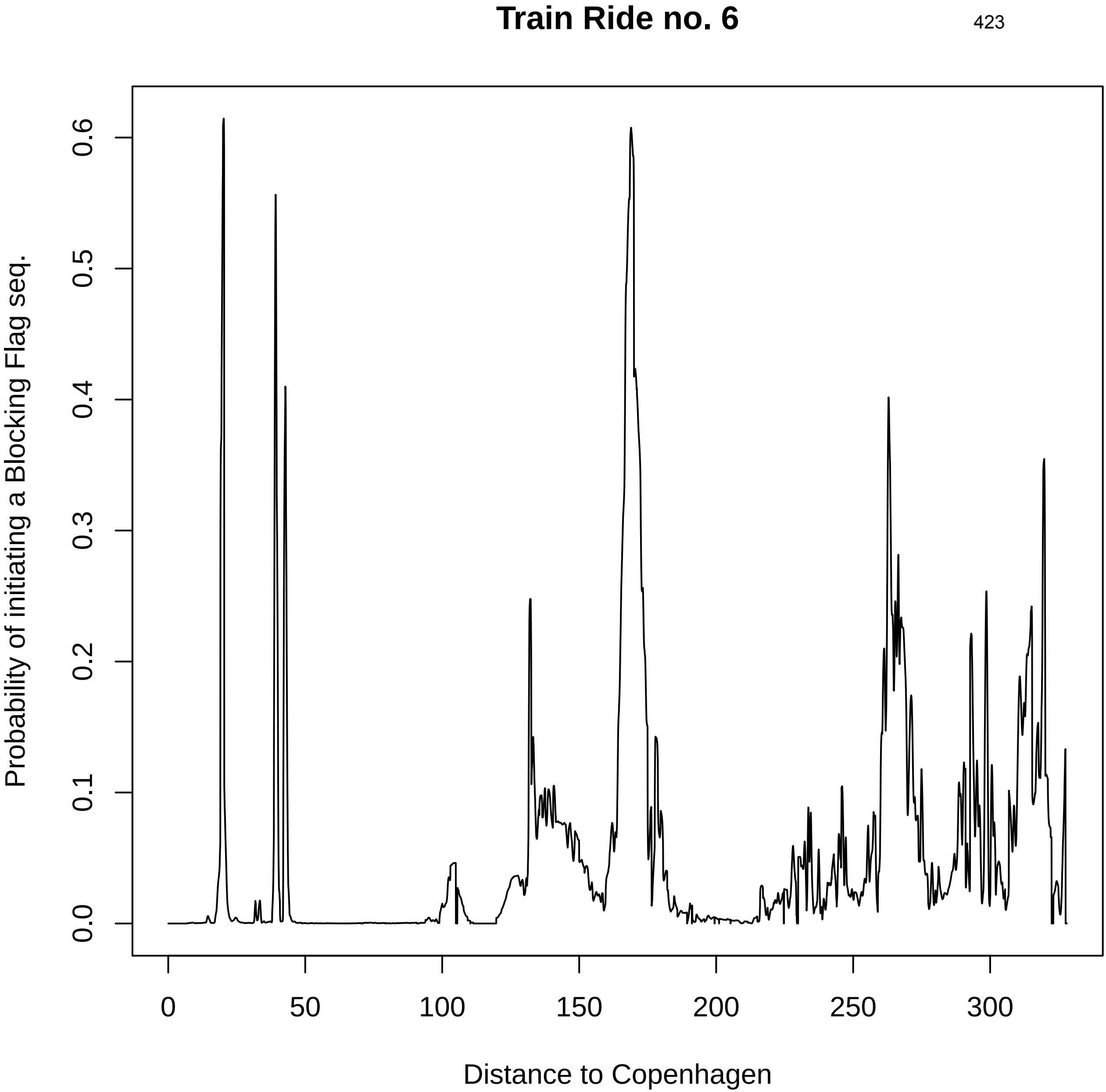
Train Ride no. 2
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 3
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

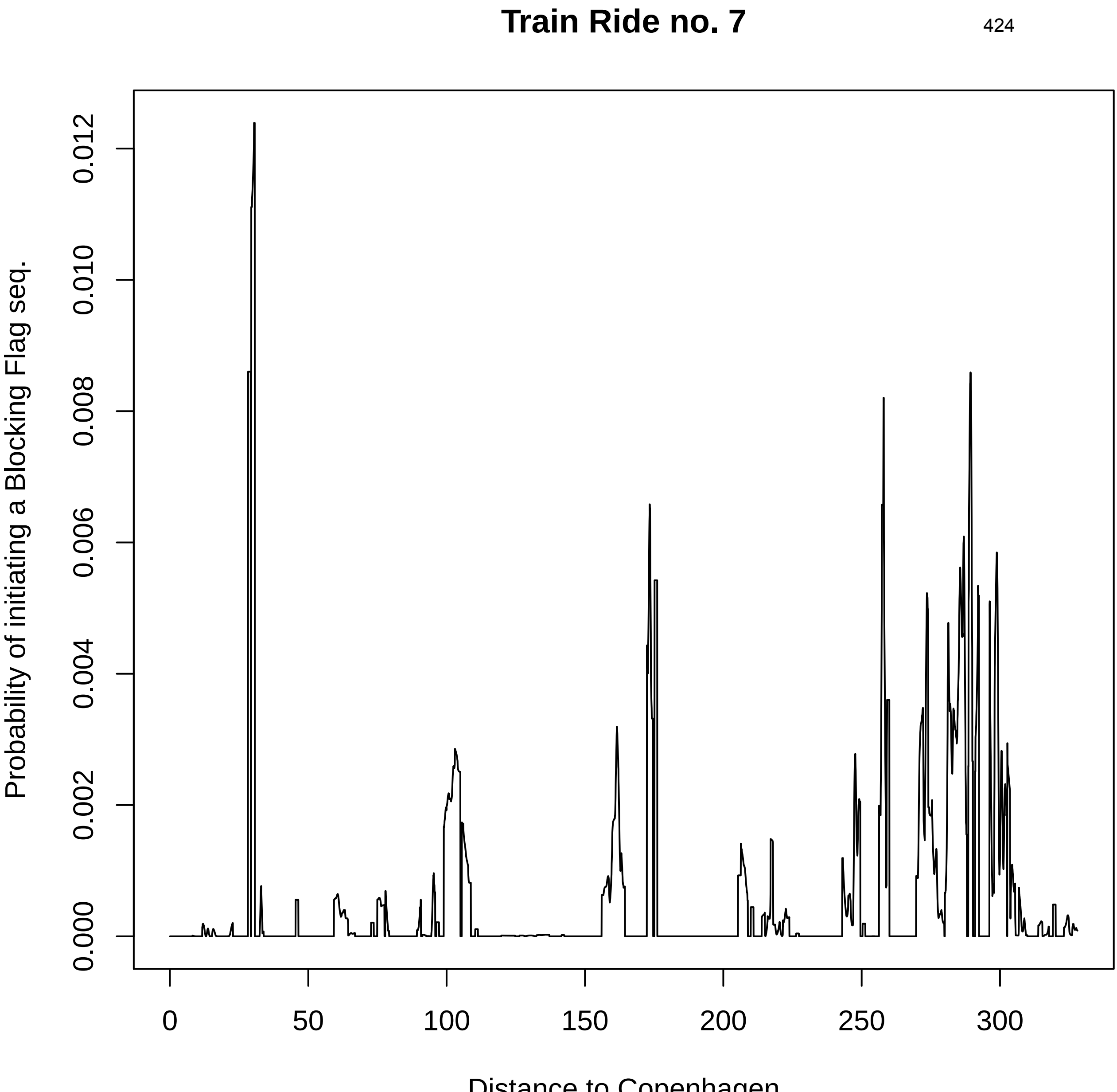


Train Ride no. 4
Probability of initiating a Blocking Flag seq.
0.00
0.01
0.02
0.03
0.04
0
50
100
150
200
250
300
Distance to Copenhagen

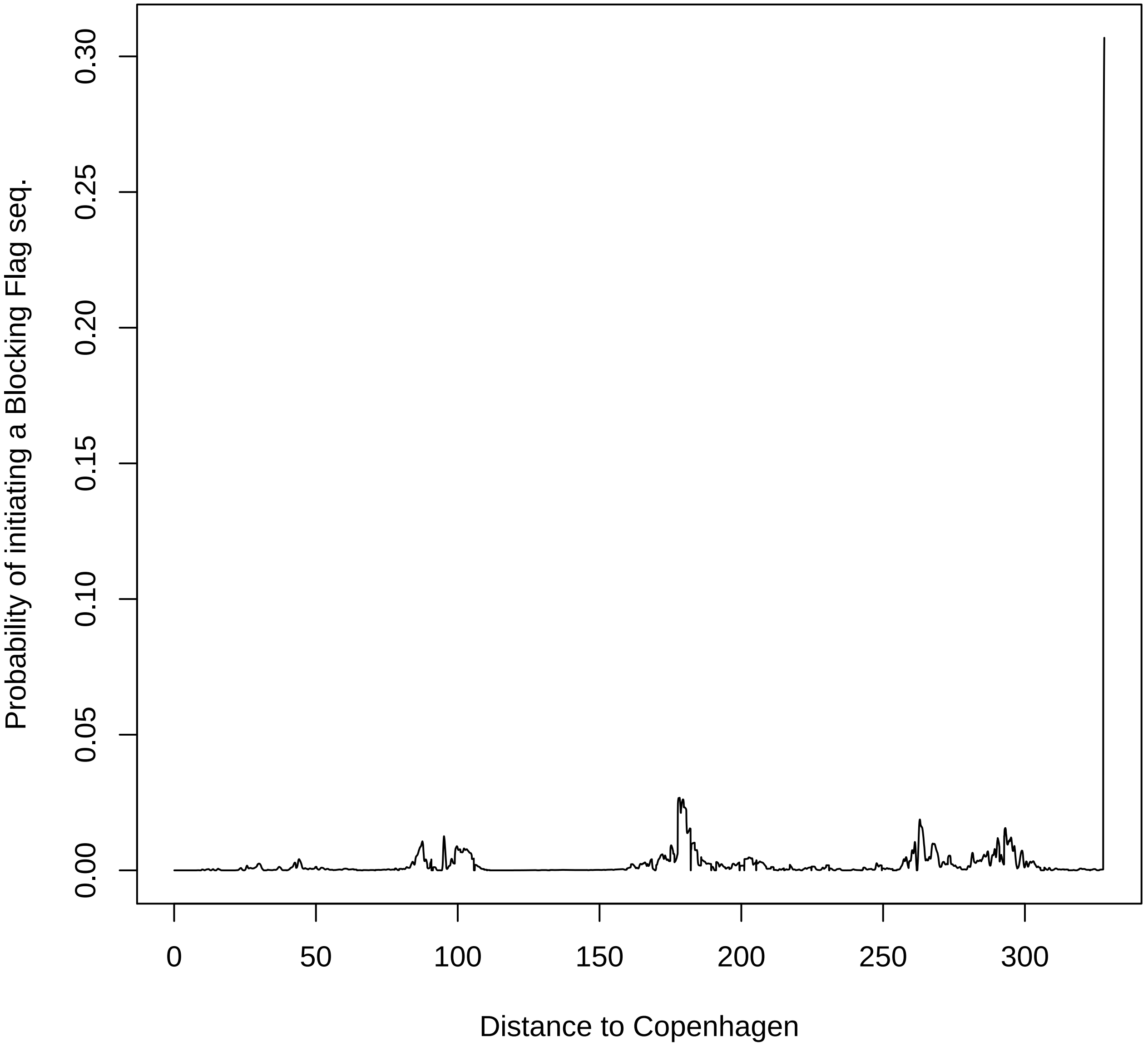

Train Ride no. 5
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

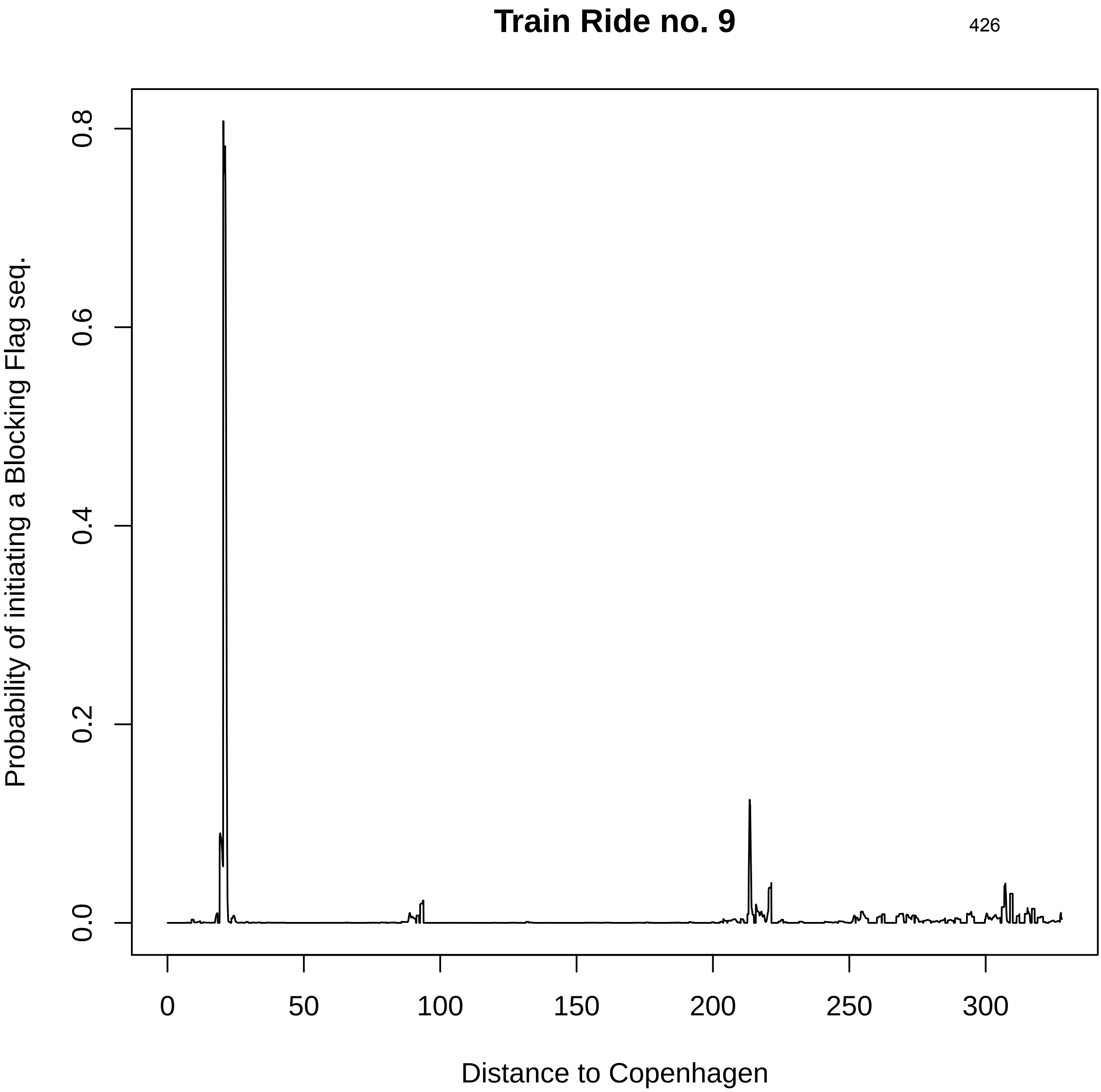


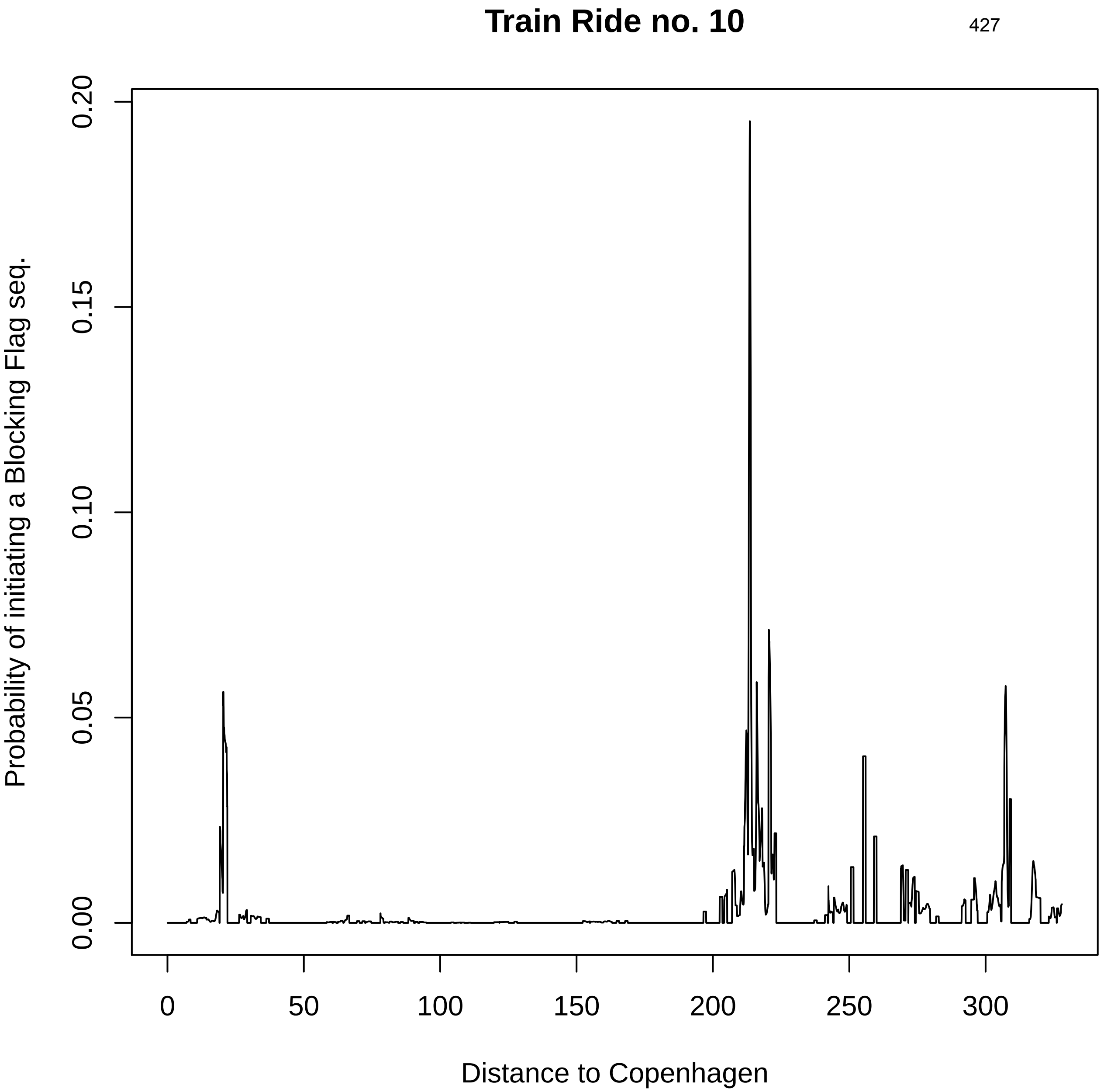
Train Ride no. 6
Probability of initiating a Blocking Flag seq.
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250
300
Distance to Copenhagen

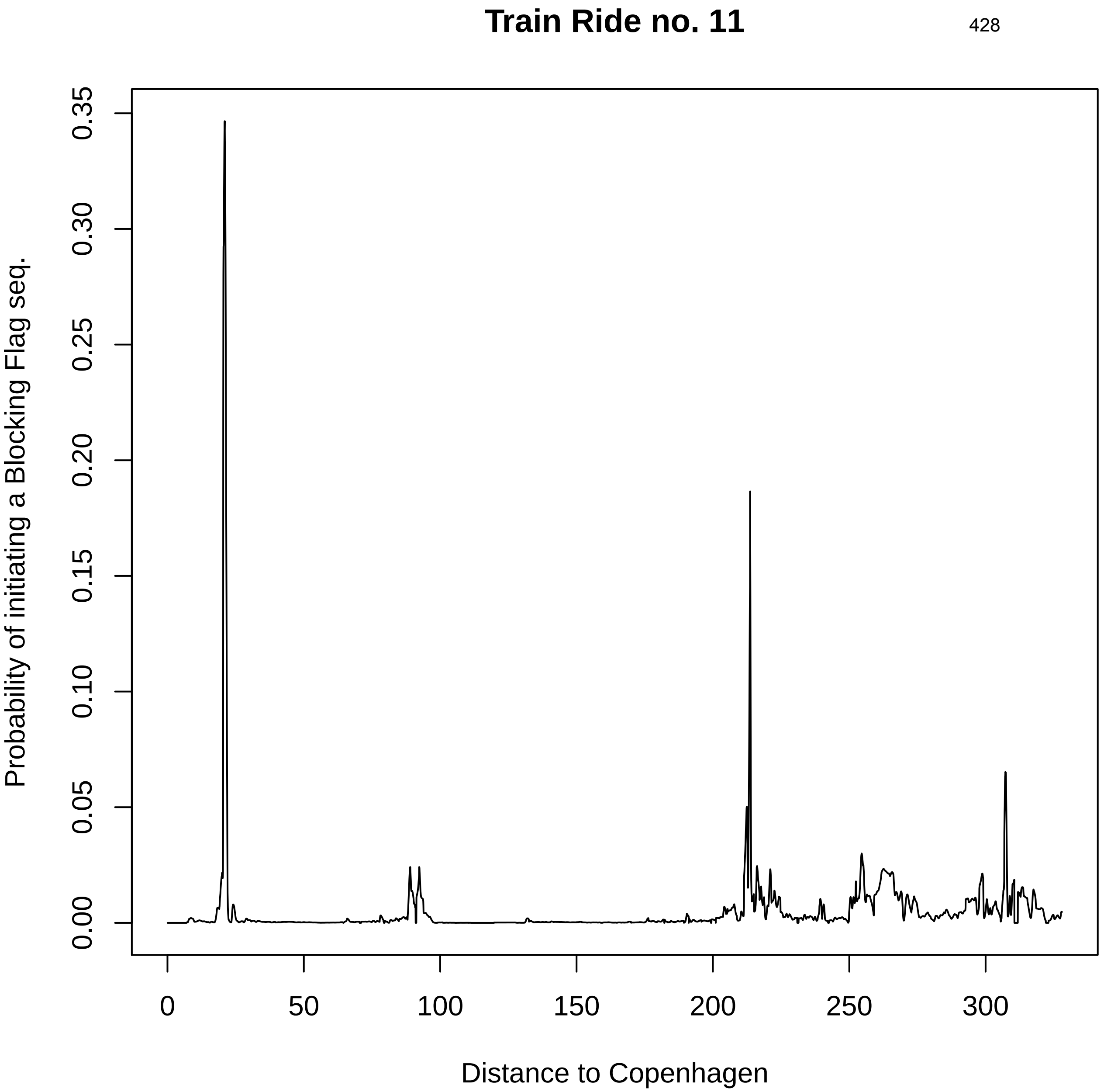

Train Ride no. 7
Probability of initiating a Blocking Flag seq.
0.000
0.002
0.004
0.006
0.008
0.010
0.012
0
50
100
150
200
250
300
Distance to Copenhagen

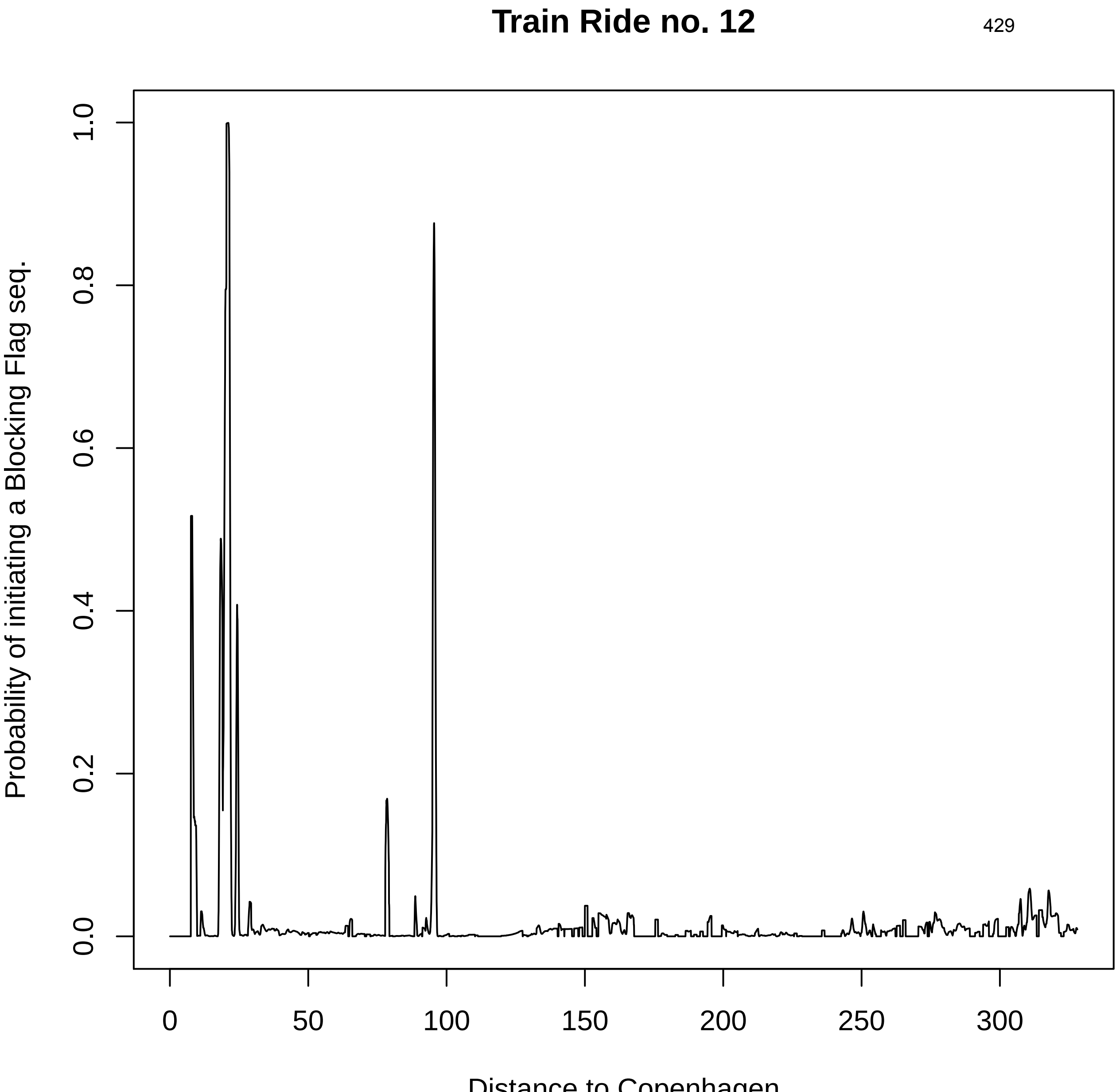
Train Ride no. 8

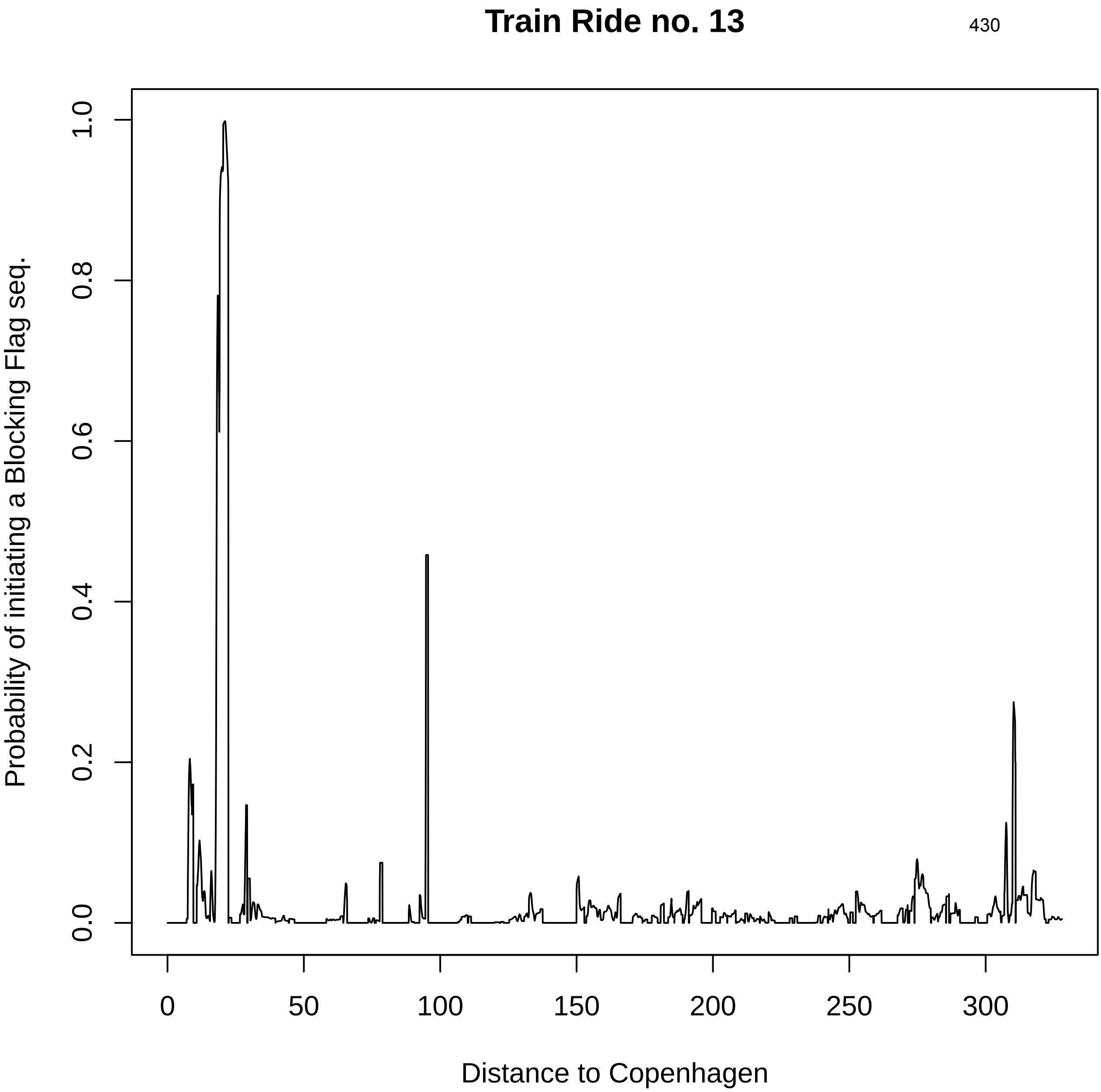



Train Ride no. 9
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

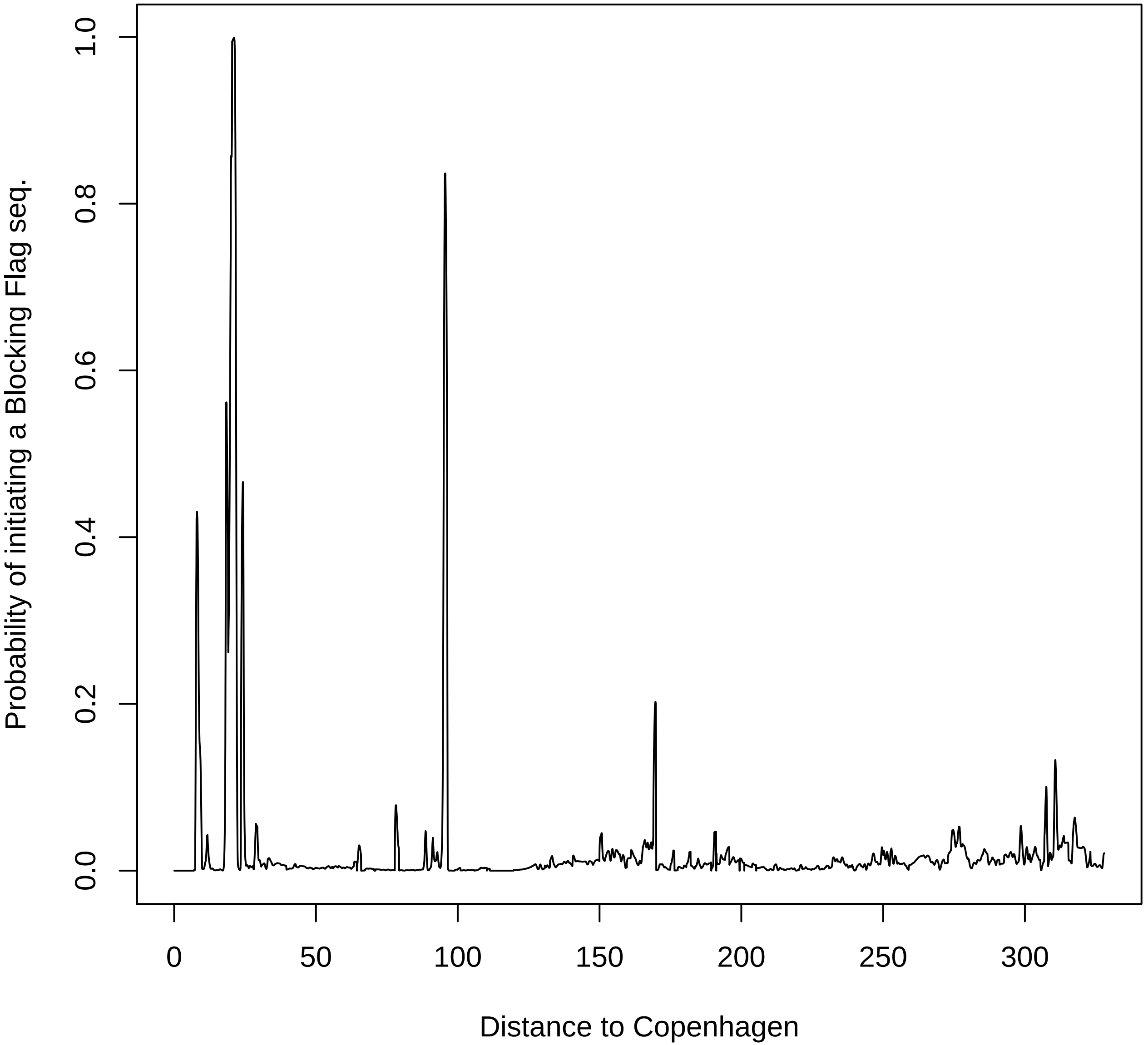

Train Ride no. 10
Probability of initiating a Blocking Flag seq.
0.00
0.05
0.10
0.15
0.20
0
50
100
150
200
250
300
Distance to Copenhagen

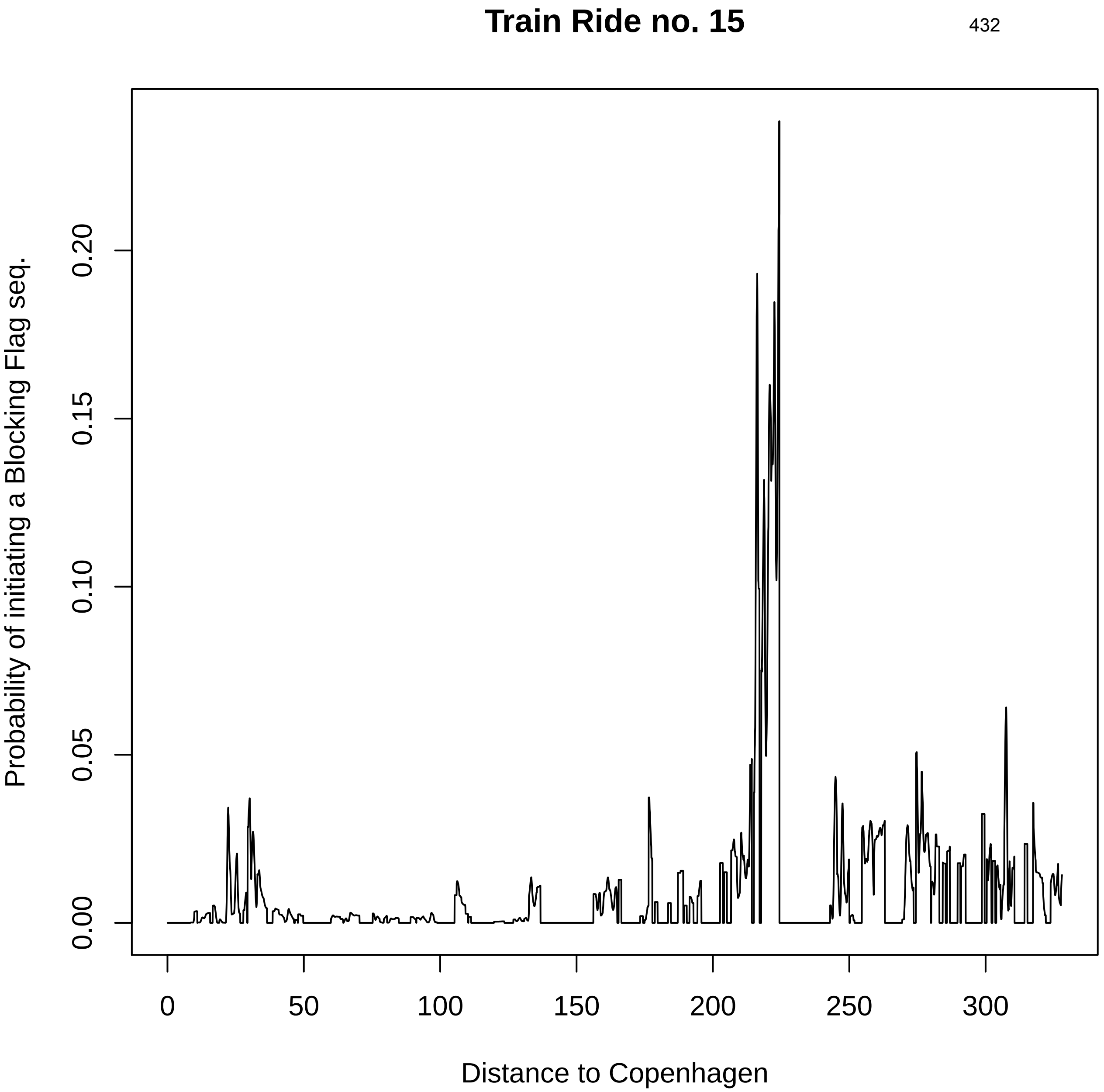

Train Ride no. 11
Probability of initiating a Blocking Flag seq.
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 12
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Distance to Copenhagen

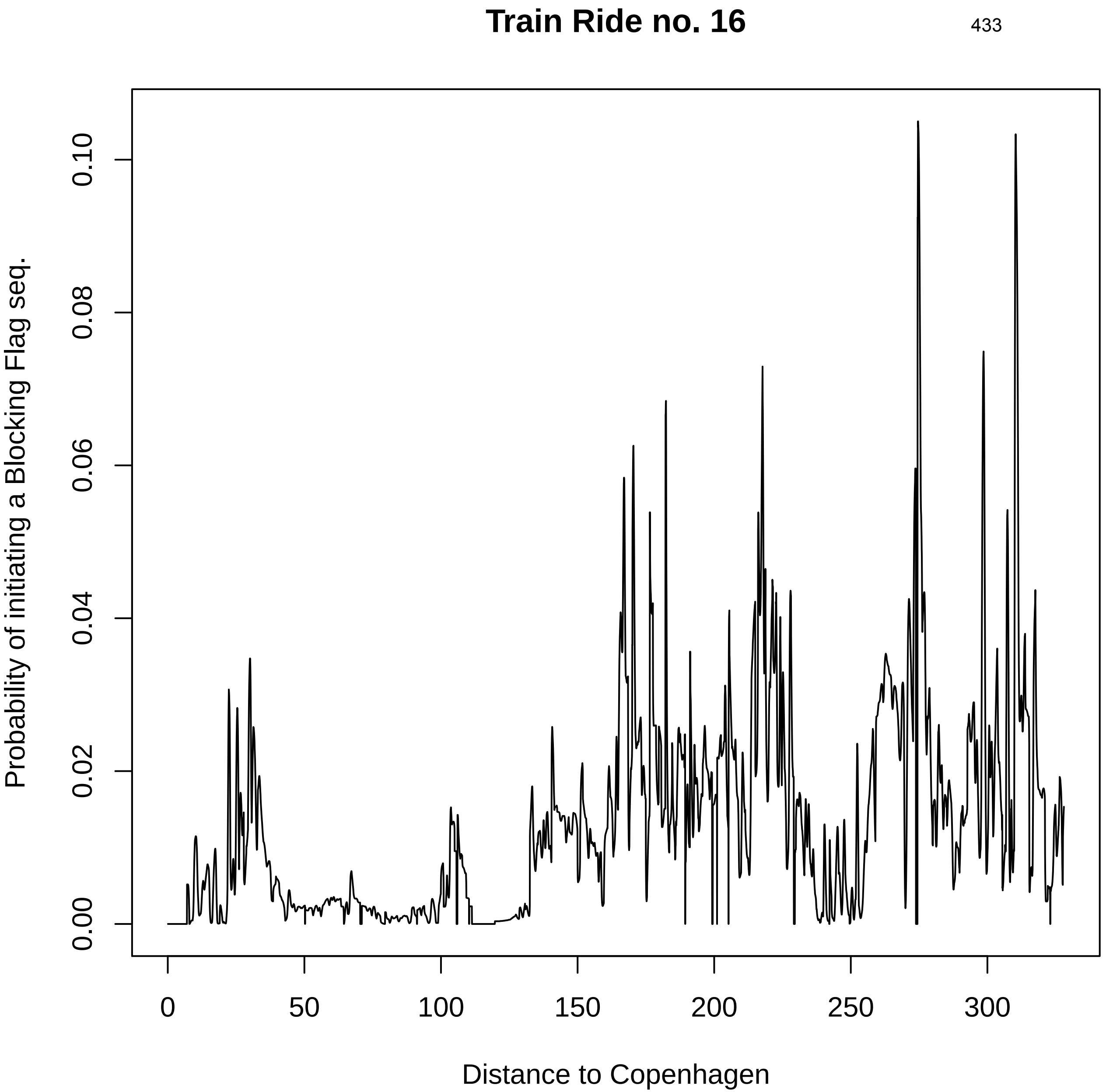

Train Ride no. 13
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Distance to Copenhagen

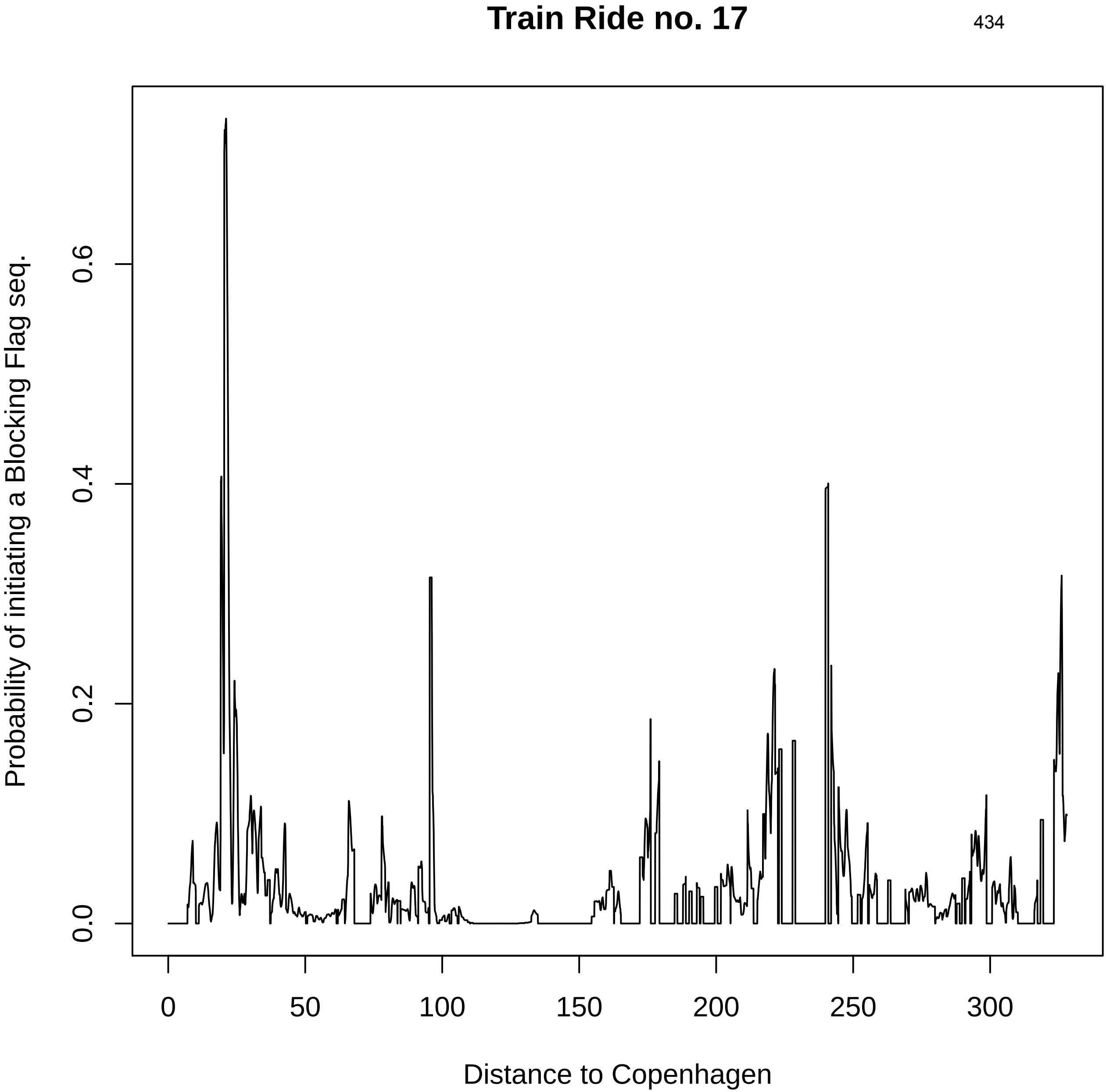
Train Ride no. 14

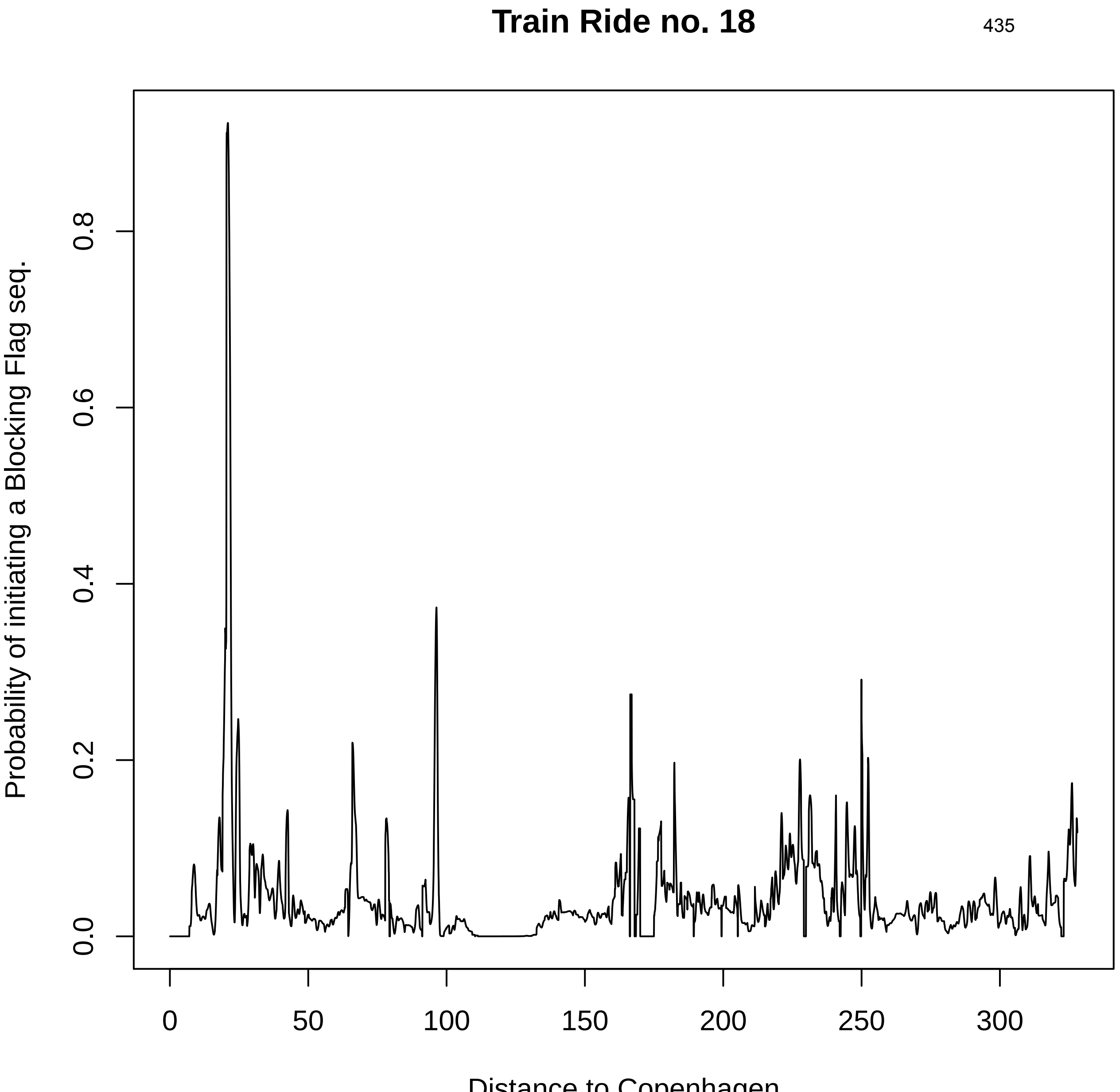


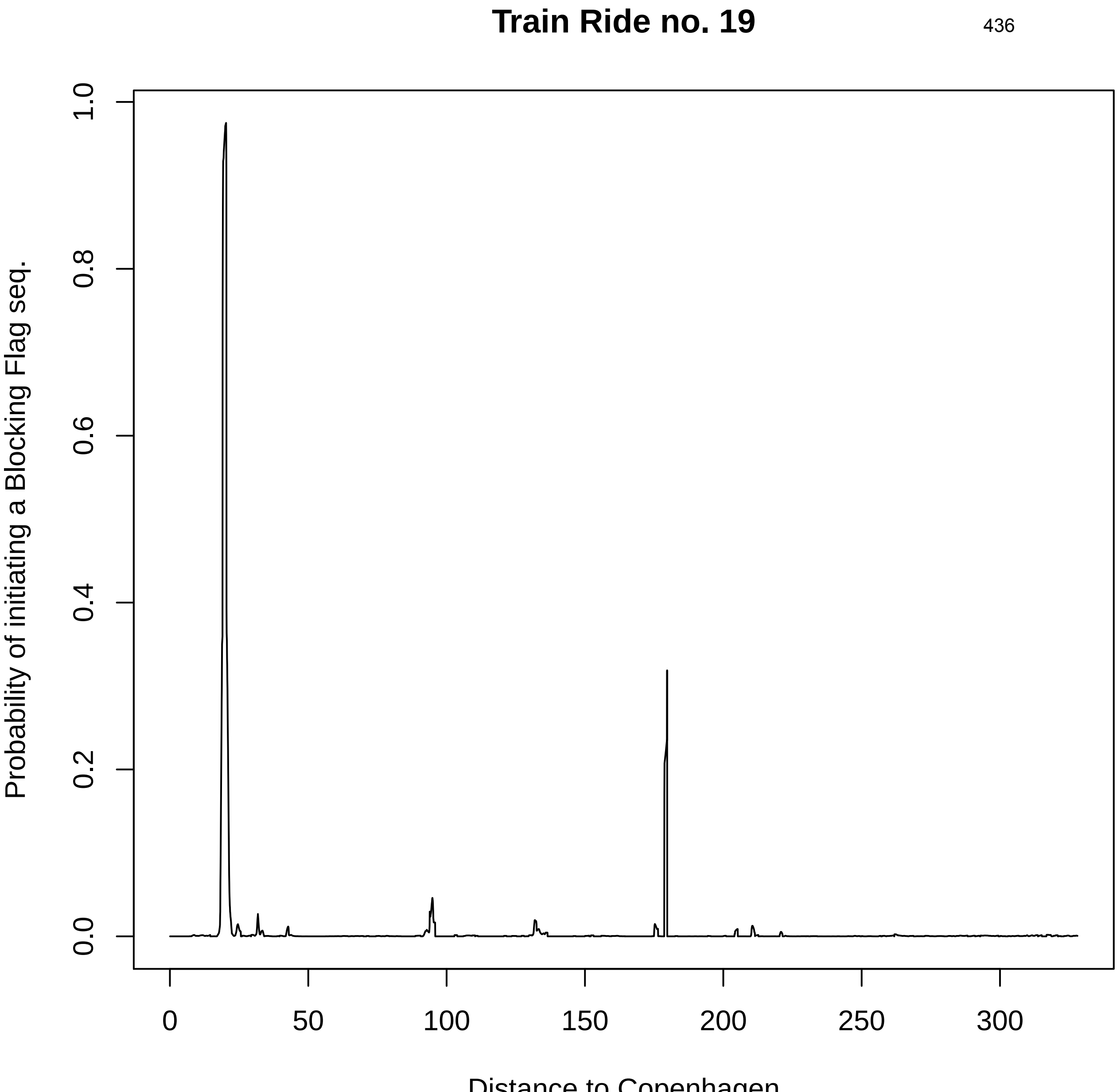


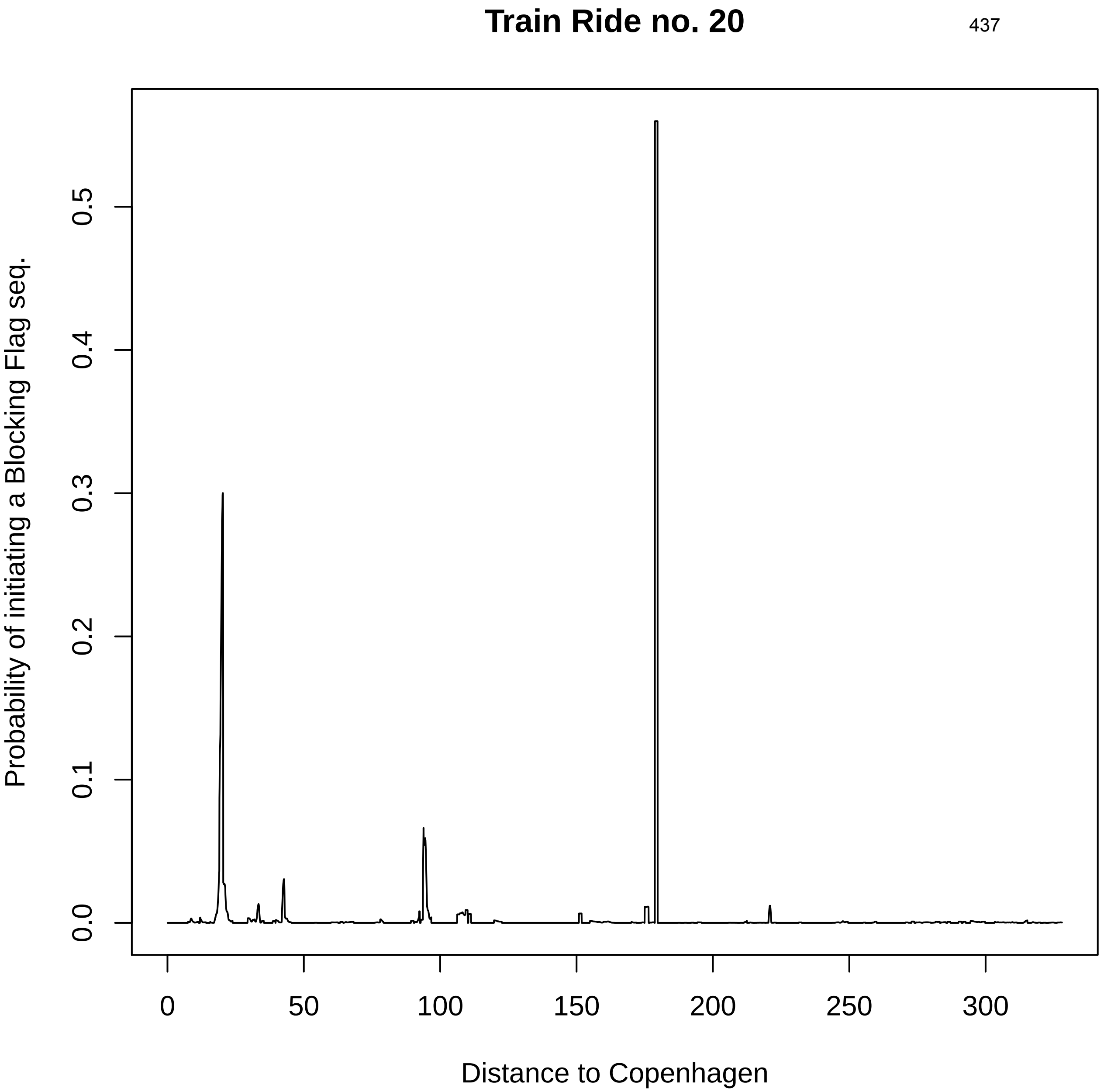
Train Ride no. 15
Probability of initiating a Blocking Flag seq.
0.00
0.05
0.10
0.15
0.20
0
50
100
150
200
250
300
Distance to Copenhagen

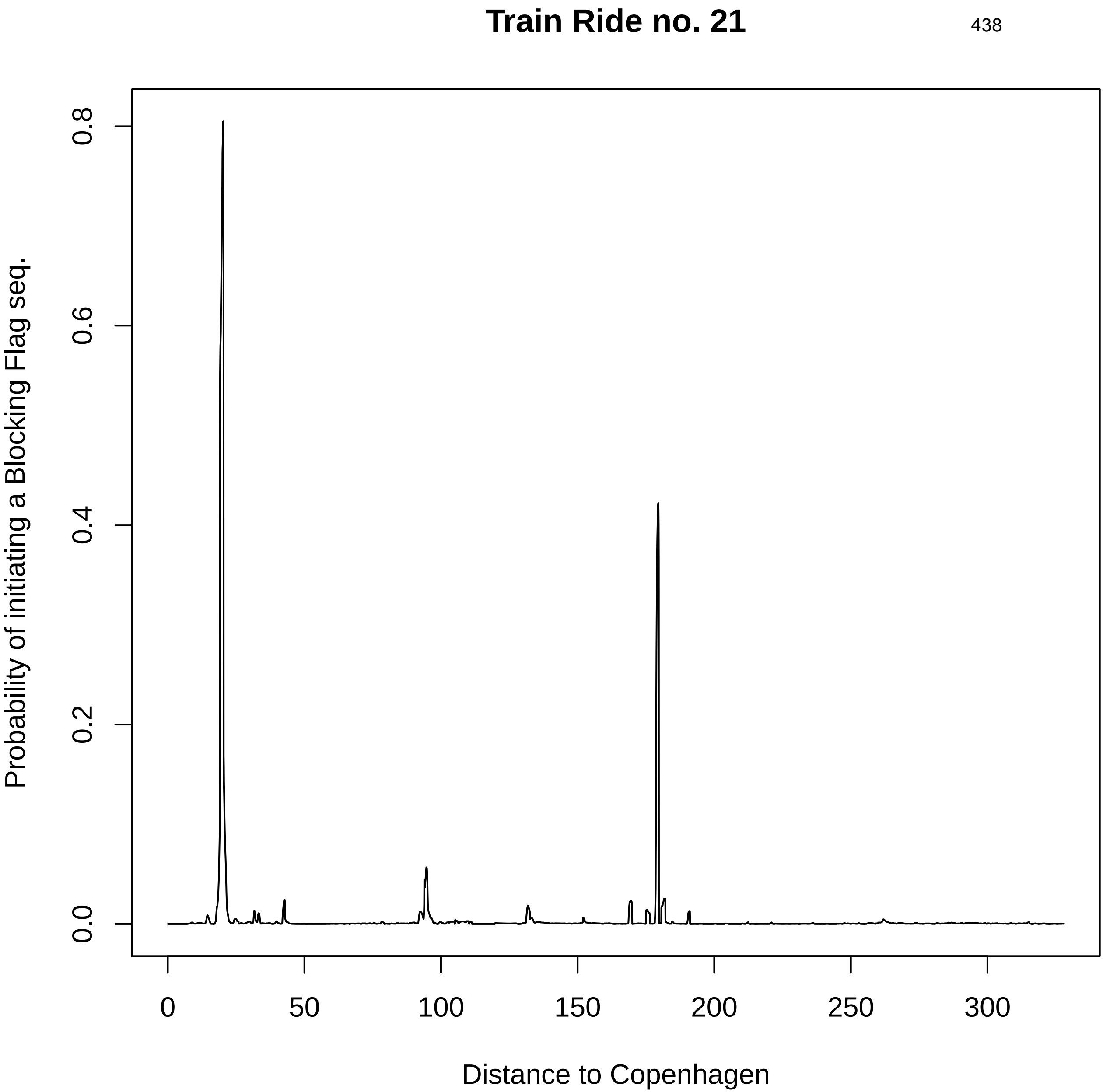

Train Ride no. 16
Probability of initiating a Blocking Flag seq.
0.00
0.02
0.04
0.06
0.08
0.10
0
50
100
150
200
250
300
Distance to Copenhagen

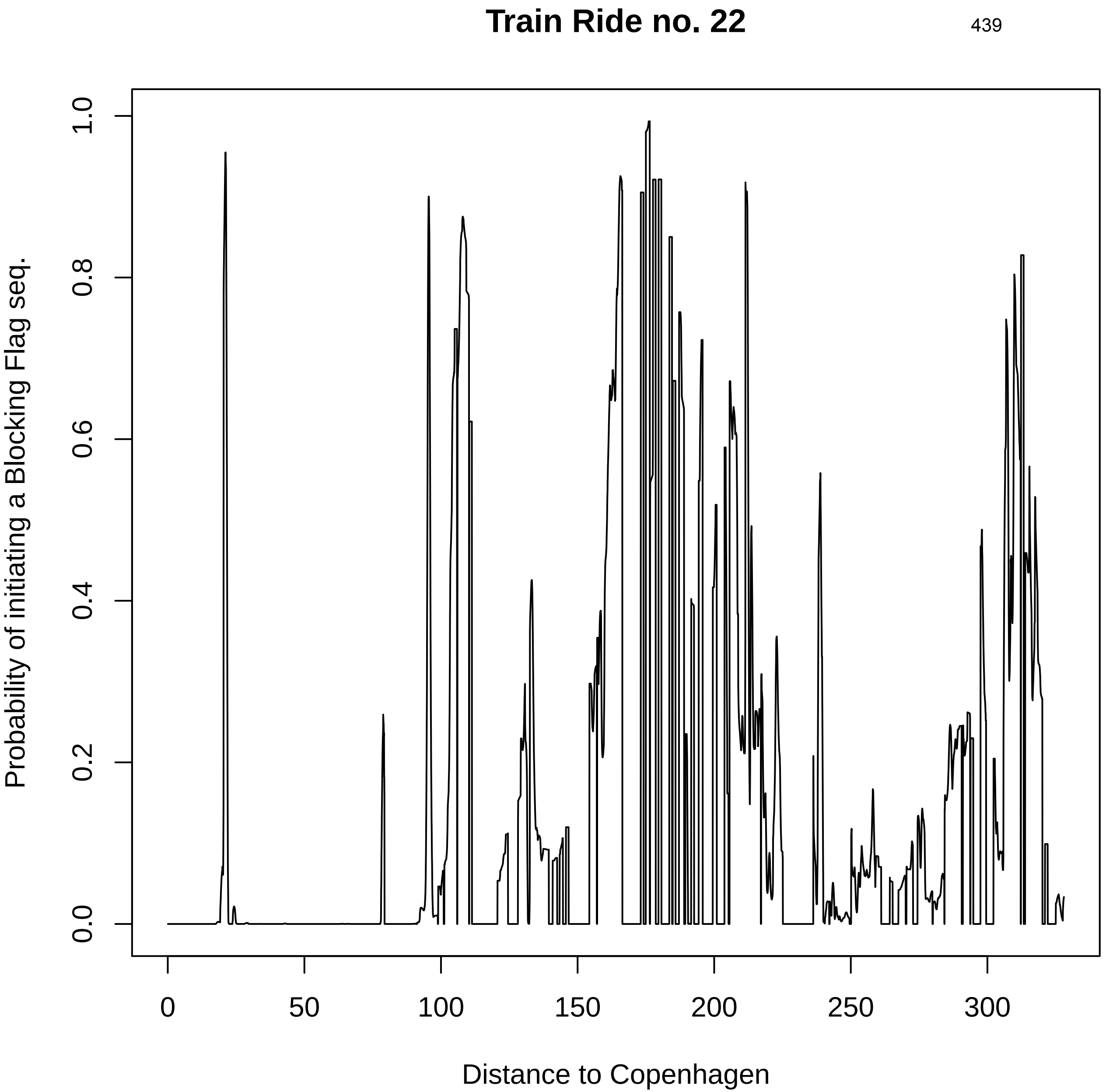

Train Ride no. 17
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 18
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

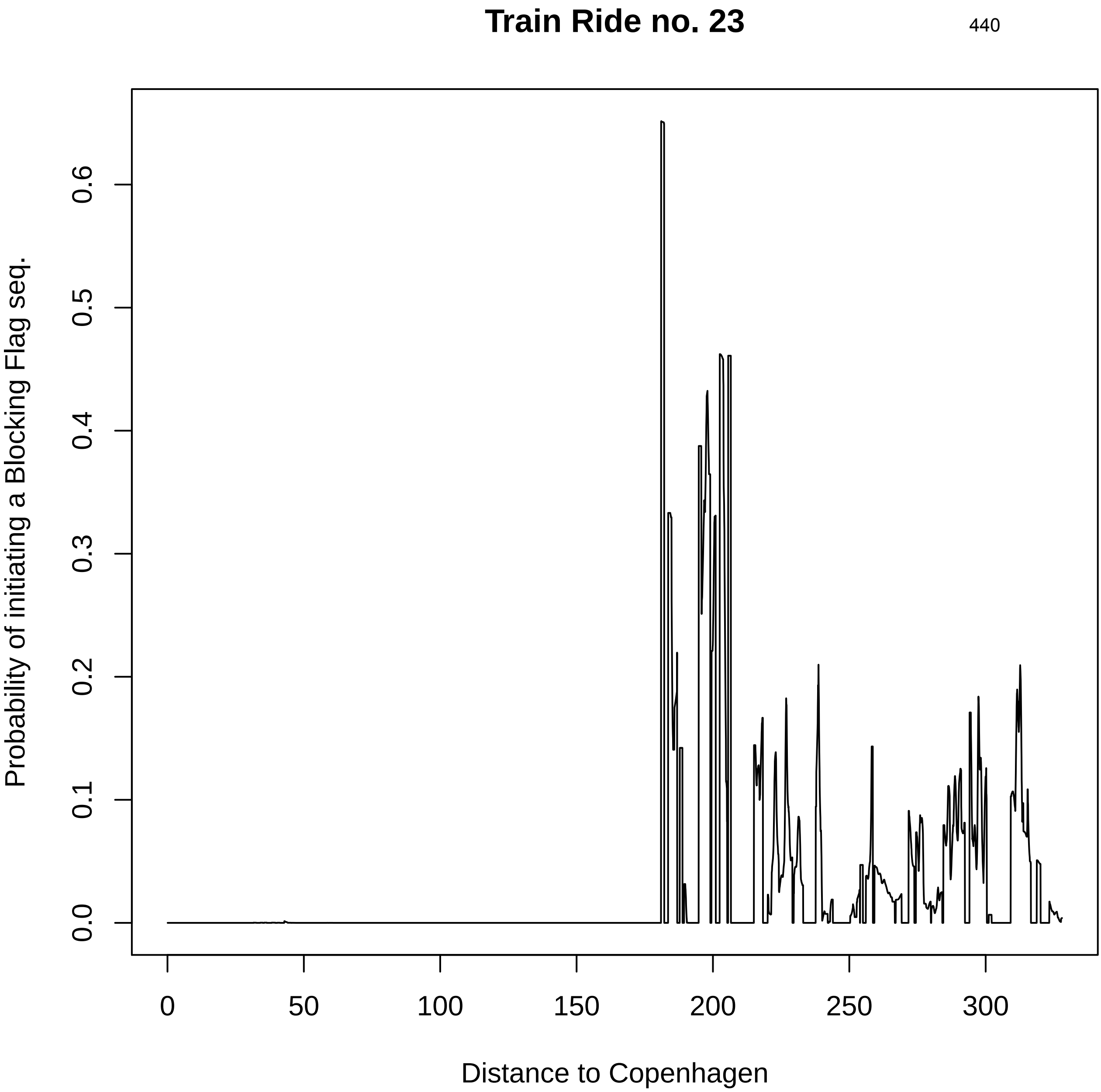

Train Ride no. 19
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Distance to Copenhagen

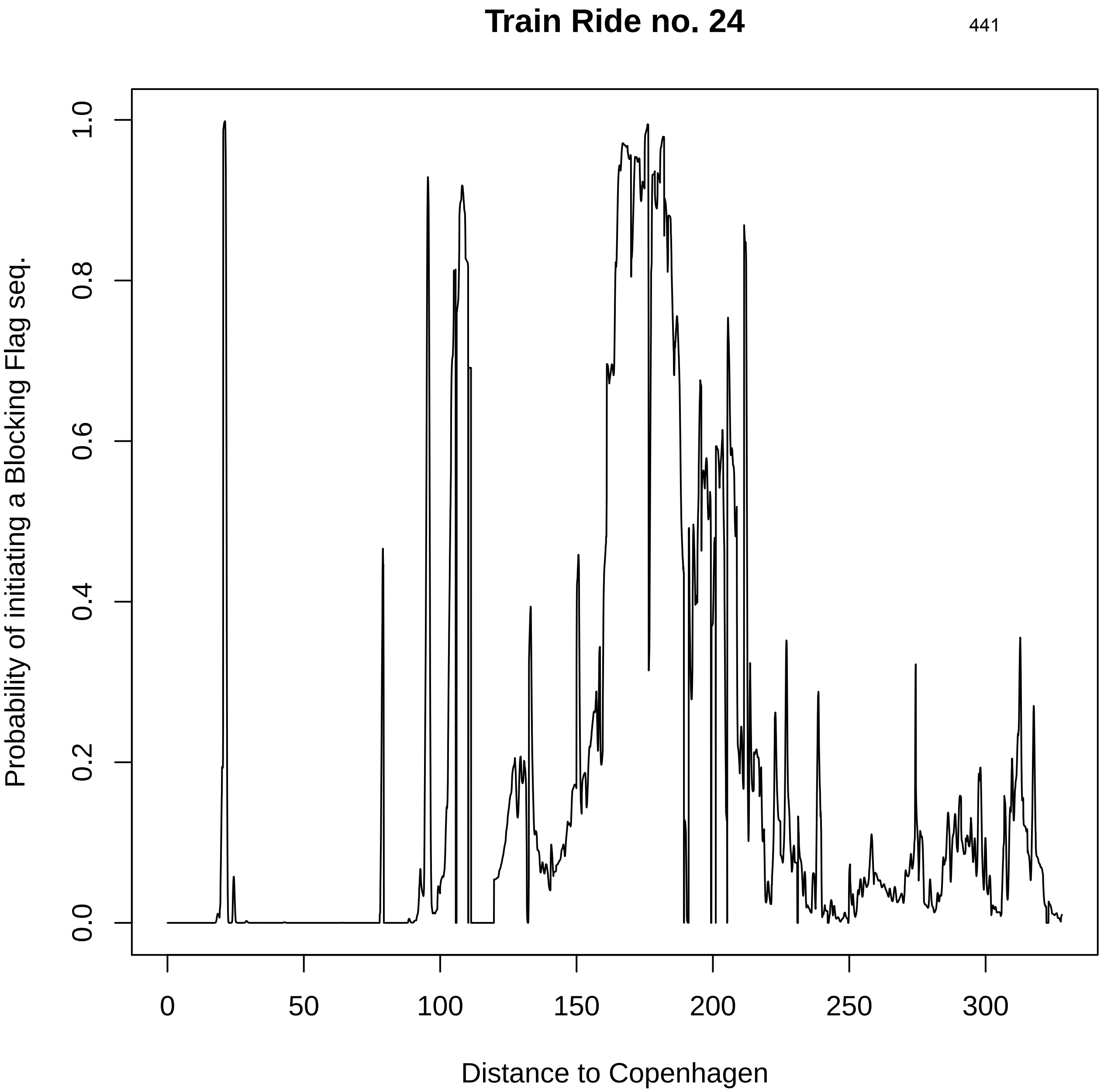

Train Ride no. 20
Probability of initiating a Blocking Flag seq.
0.0
0.1
0.2
0.3
0.4
0.5
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 21
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
0
50
100
150
200
250
300
Distance to Copenhagen

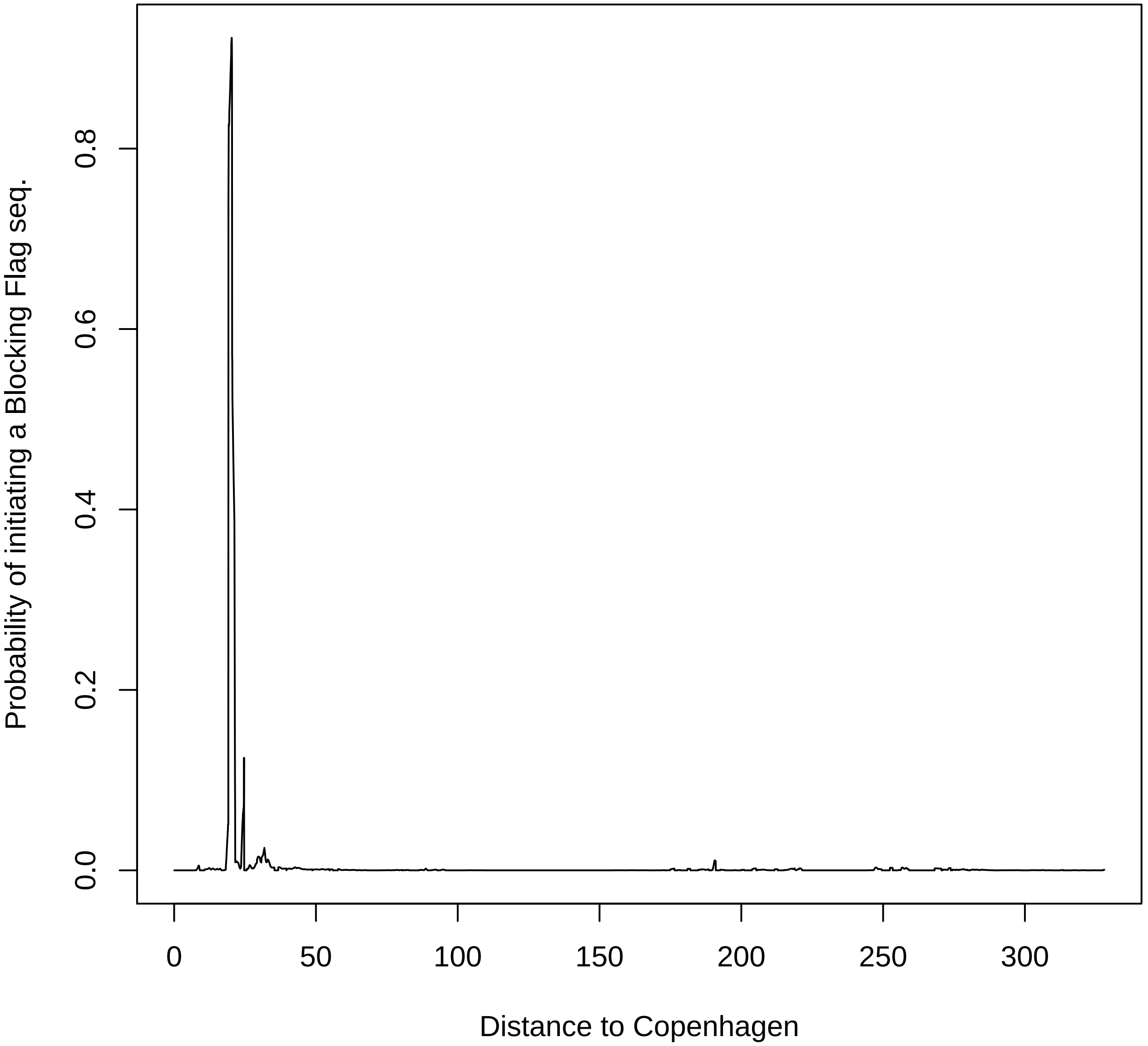


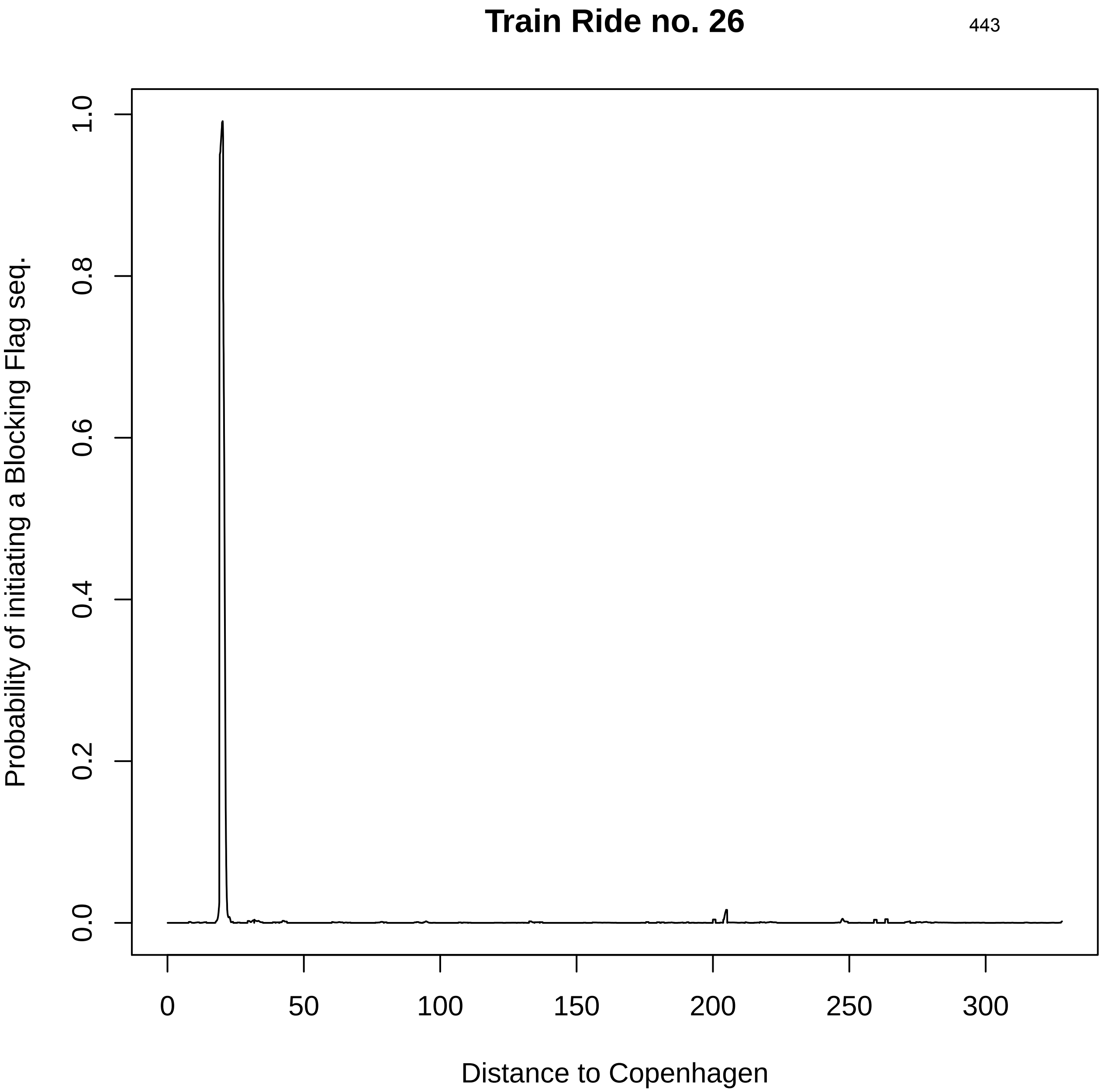
Train Ride no. 22
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Distance to Copenhagen

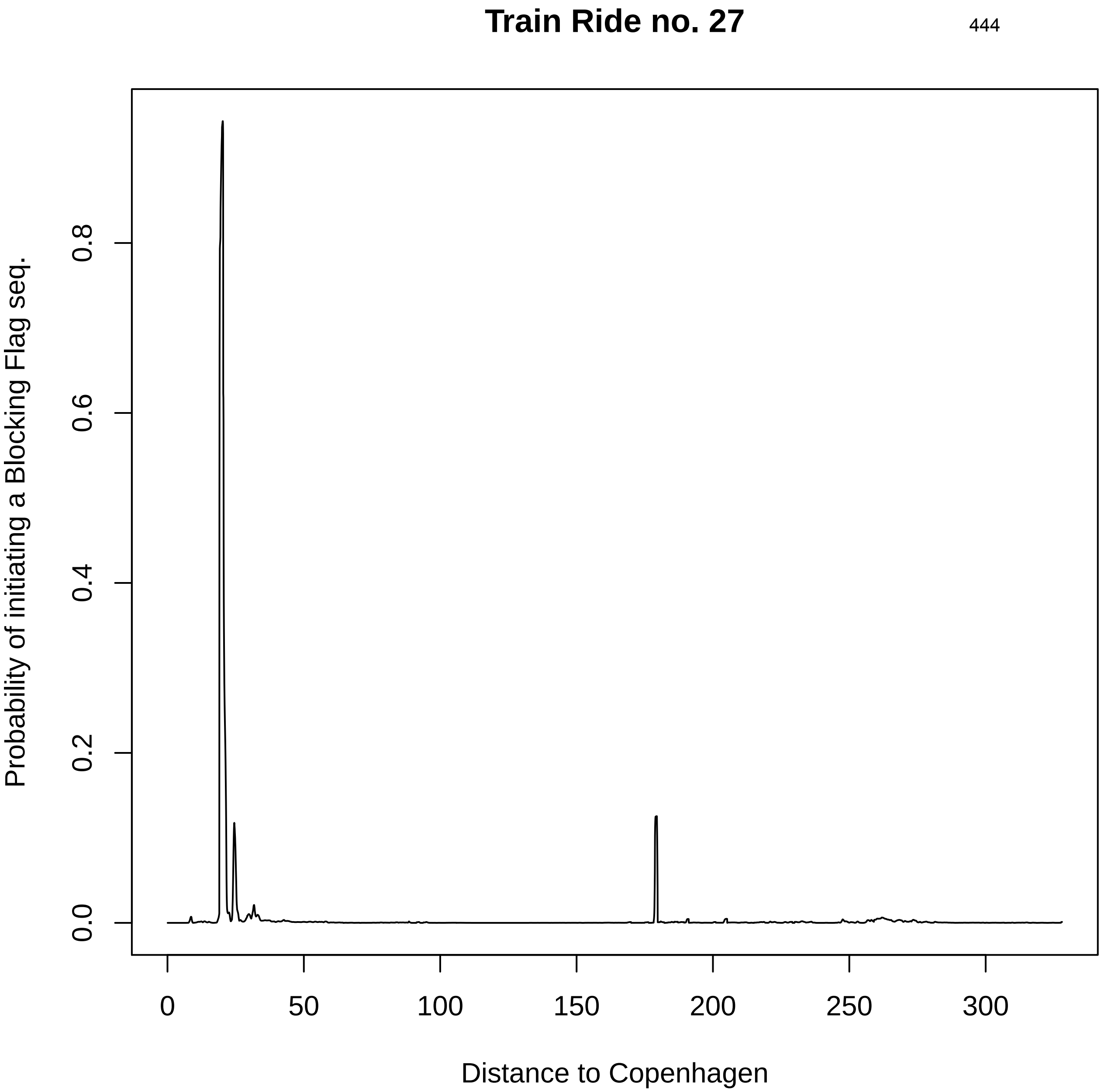

Train Ride no. 23
Probability of initiating a Blocking Flag seq.
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250
300
Distance to Copenhagen

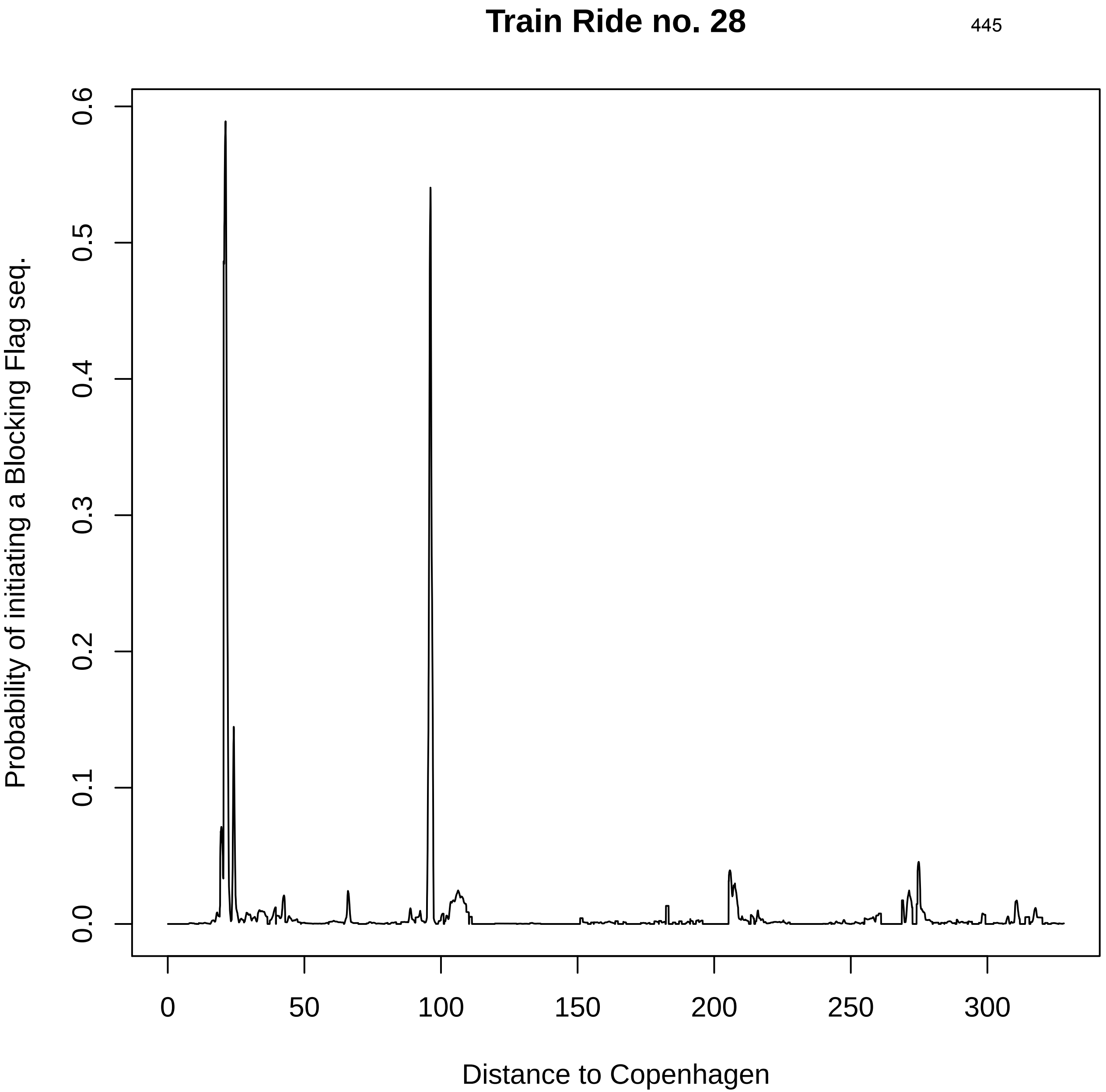

Train Ride no. 24
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
1.0
0
50
100
150
200
250
300
Distance to Copenhagen

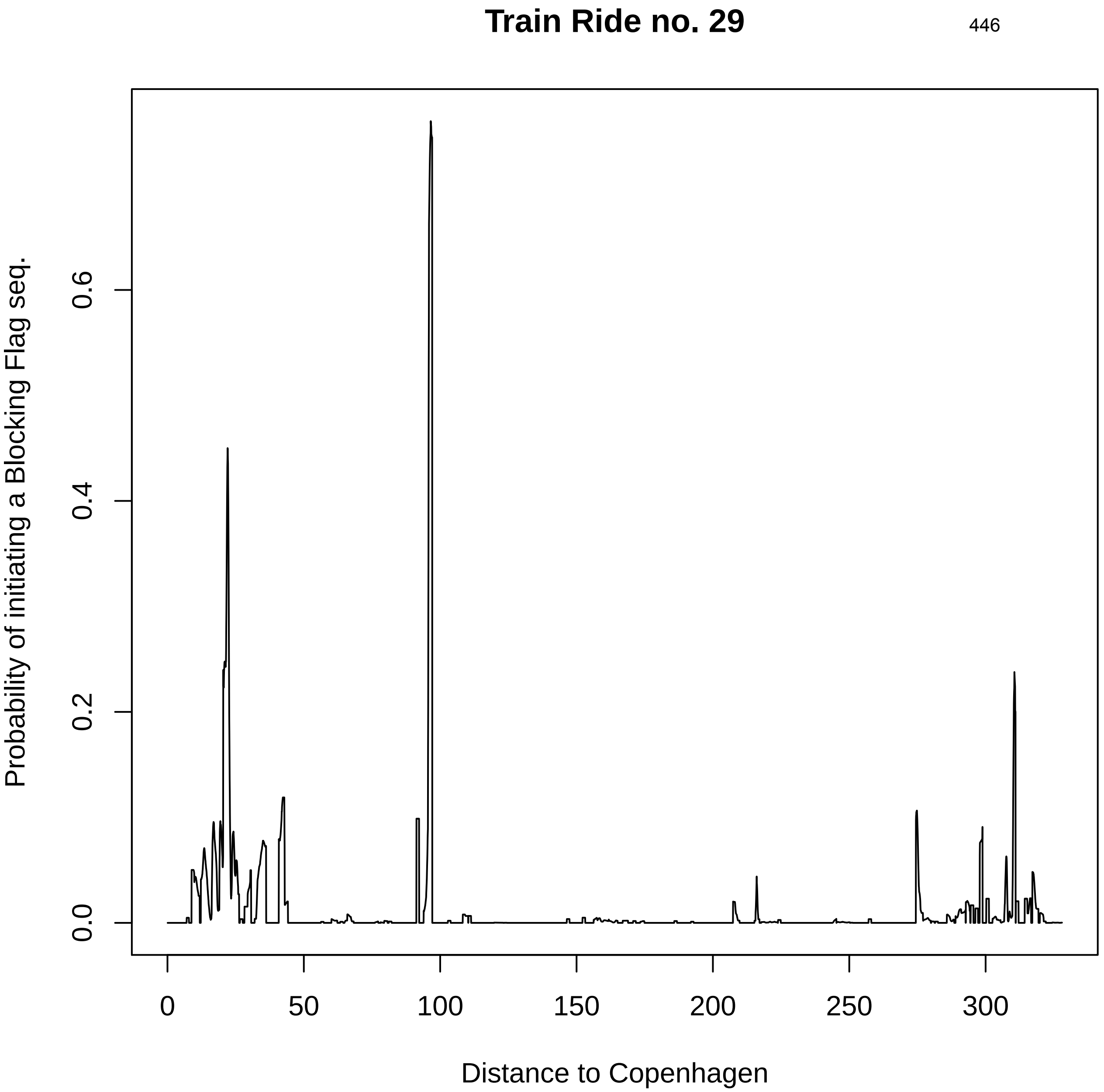
Train Ride no. 25

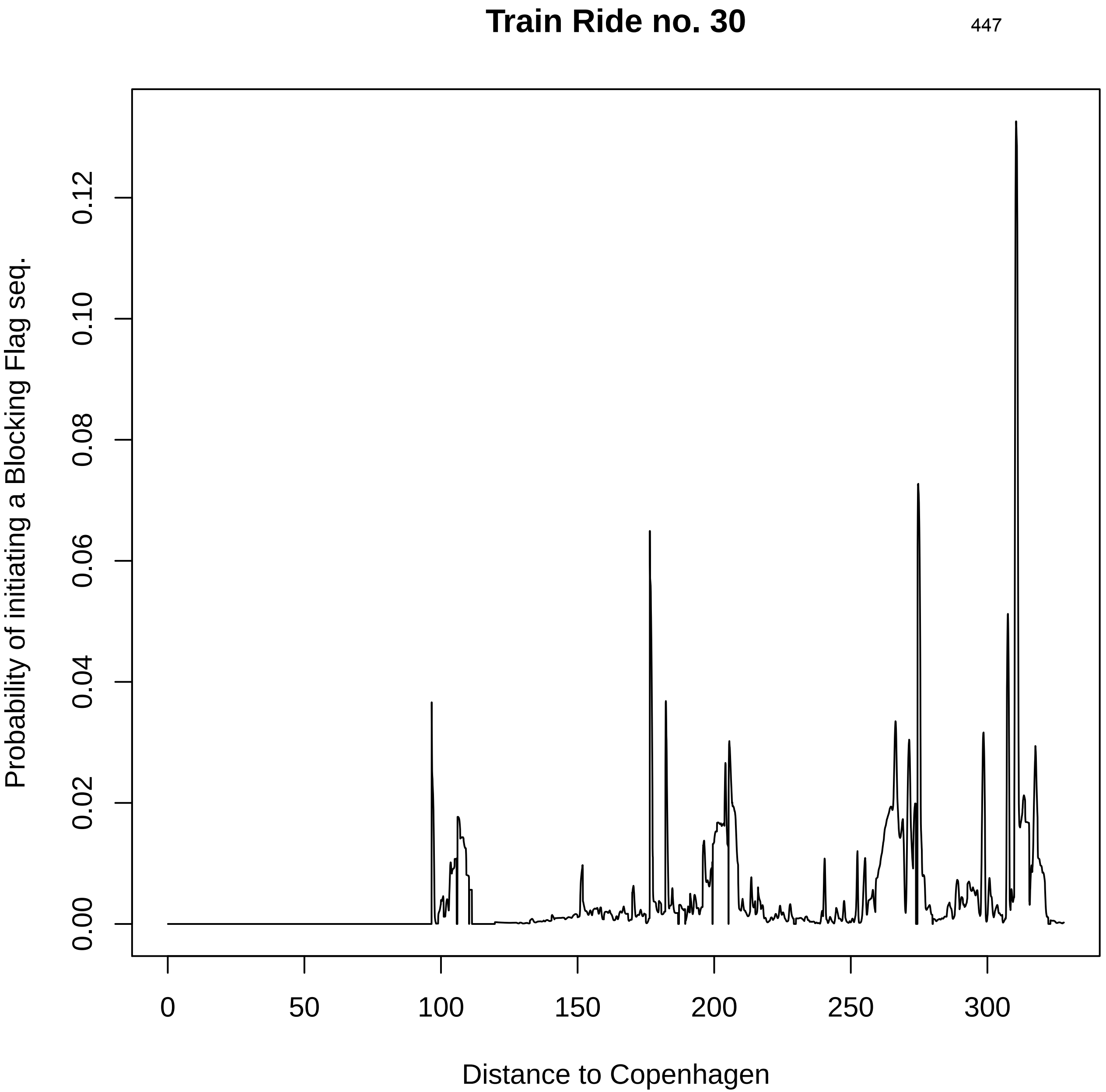



Train Ride no. 26
Probability of initiating a Blocking Flag seq.
1.0
0.8
0.6
0.4
0.2
0.0
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 27
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0.8
Distance to Copenhagen
0
50
100
150
200
250
300

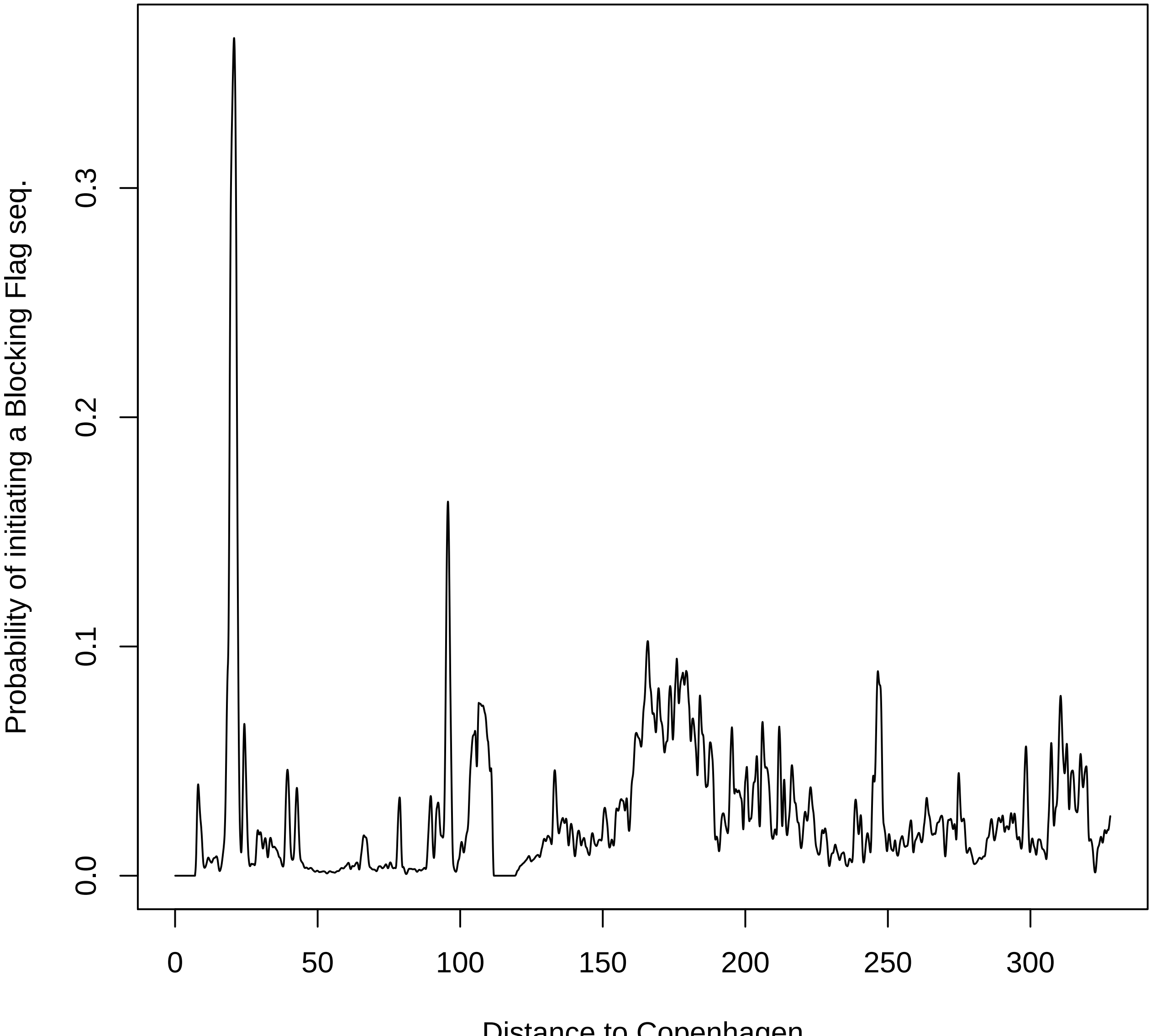

Train Ride no. 28
Probability of initiating a Blocking Flag seq.
0.0
0.1
0.2
0.3
0.4
0.5
0.6
0
50
100
150
200
250
300
Distance to Copenhagen


Train Ride no. 29
Probability of initiating a Blocking Flag seq.
0.0
0.2
0.4
0.6
0
50
100
150
200
250
300
Distance to Copenhagen



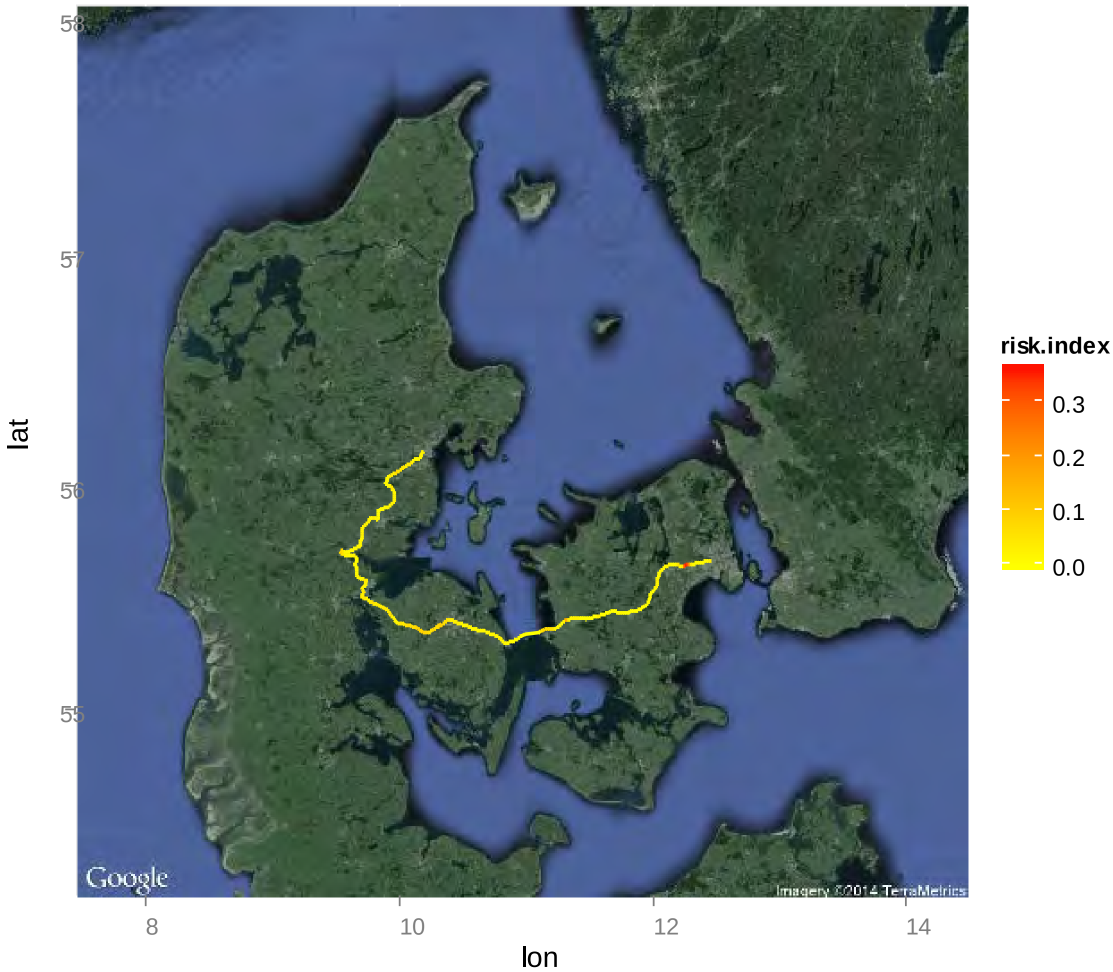
Train Ride no. 30
Probability of initiating a Blocking Flag seq.
0.00
0.02
0.04
0.06
0.08
0.10
0.12
0
50
100
150
200
250
300
Distance to Copenhagen

All Train Rides



Annex J: The probability of initiating a Blocking Flag sequence at 180 km/h as a function of distance to Copenhagen Central Station, weighted together and visualized in geographical maps.

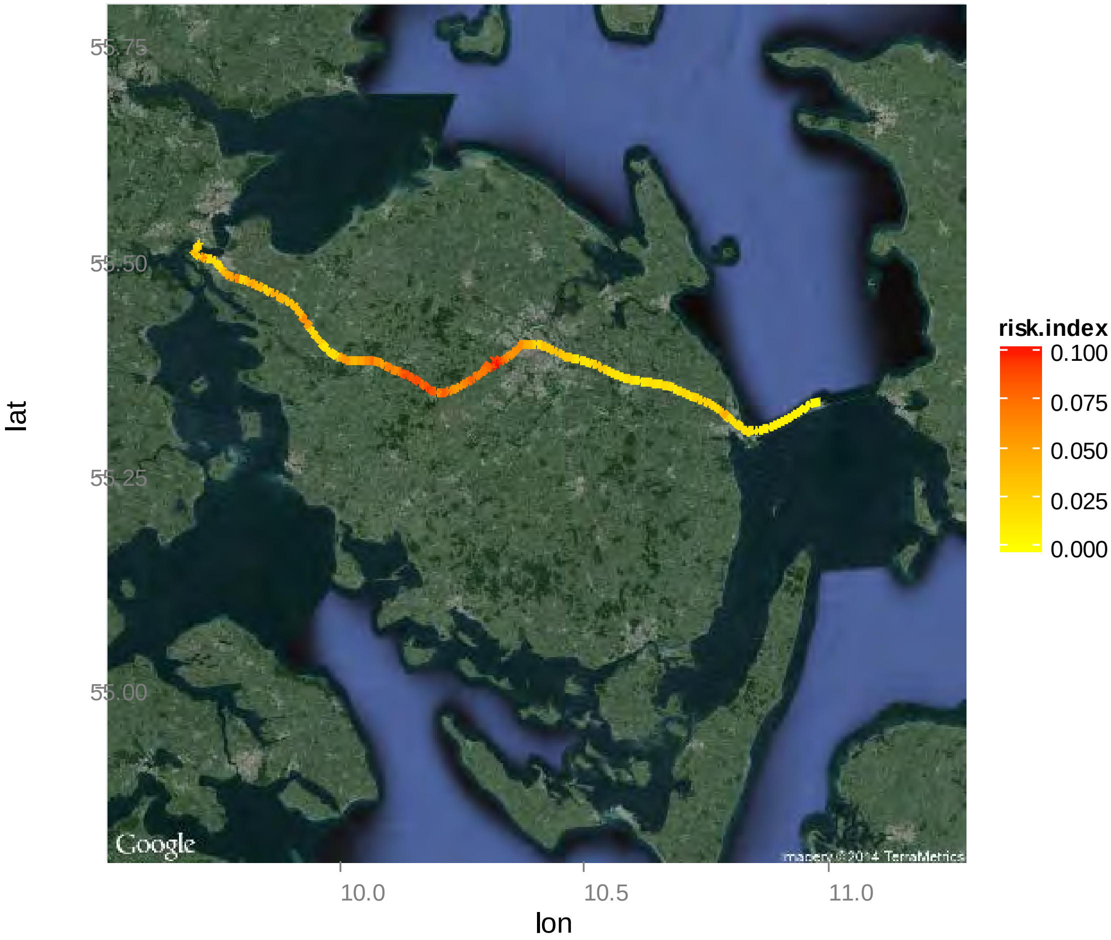
Copenhagen-Århus map:



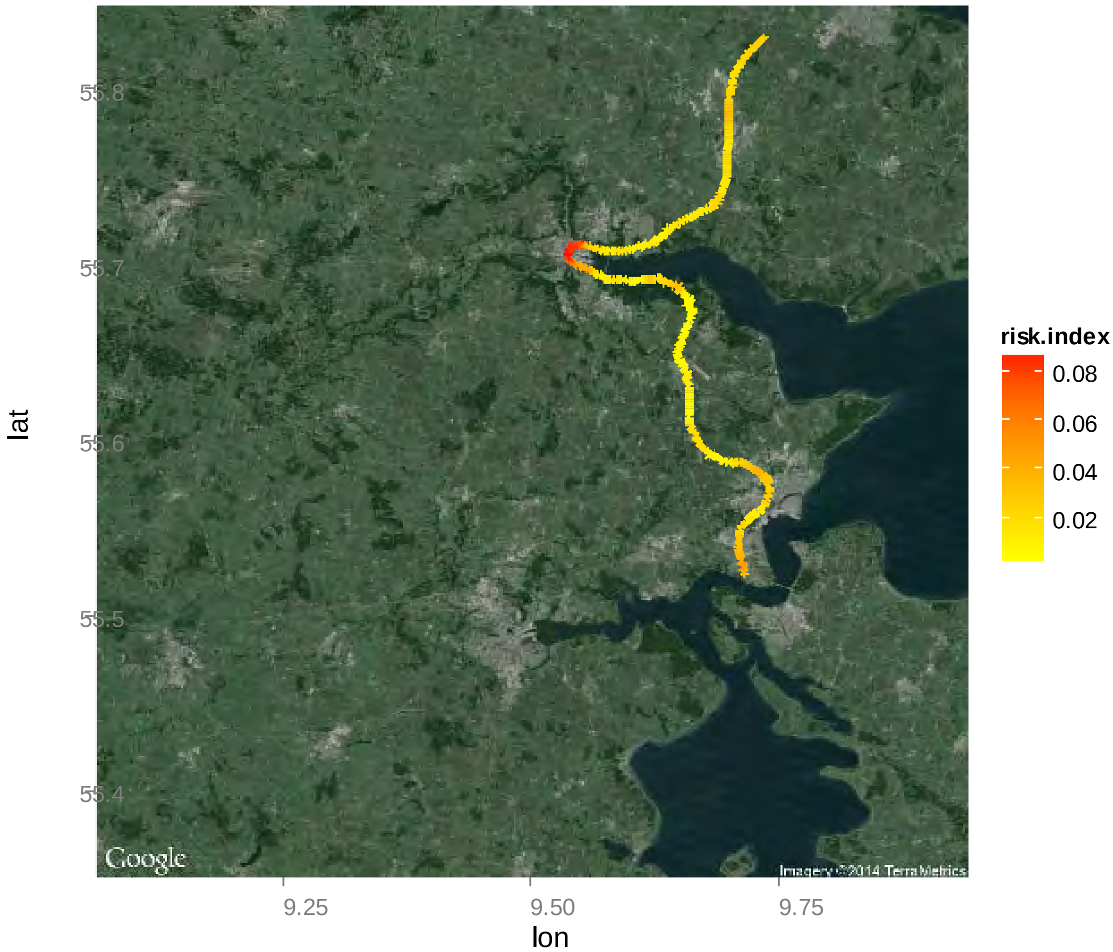
Zealand map:

risk.index
0.3
0.2
0.1
0.0
lat
55.75
55.50
55.25
55.00
lon
11.0
11.5
12.0
12.5
Google
Imagery ©2014 TerraMetrics

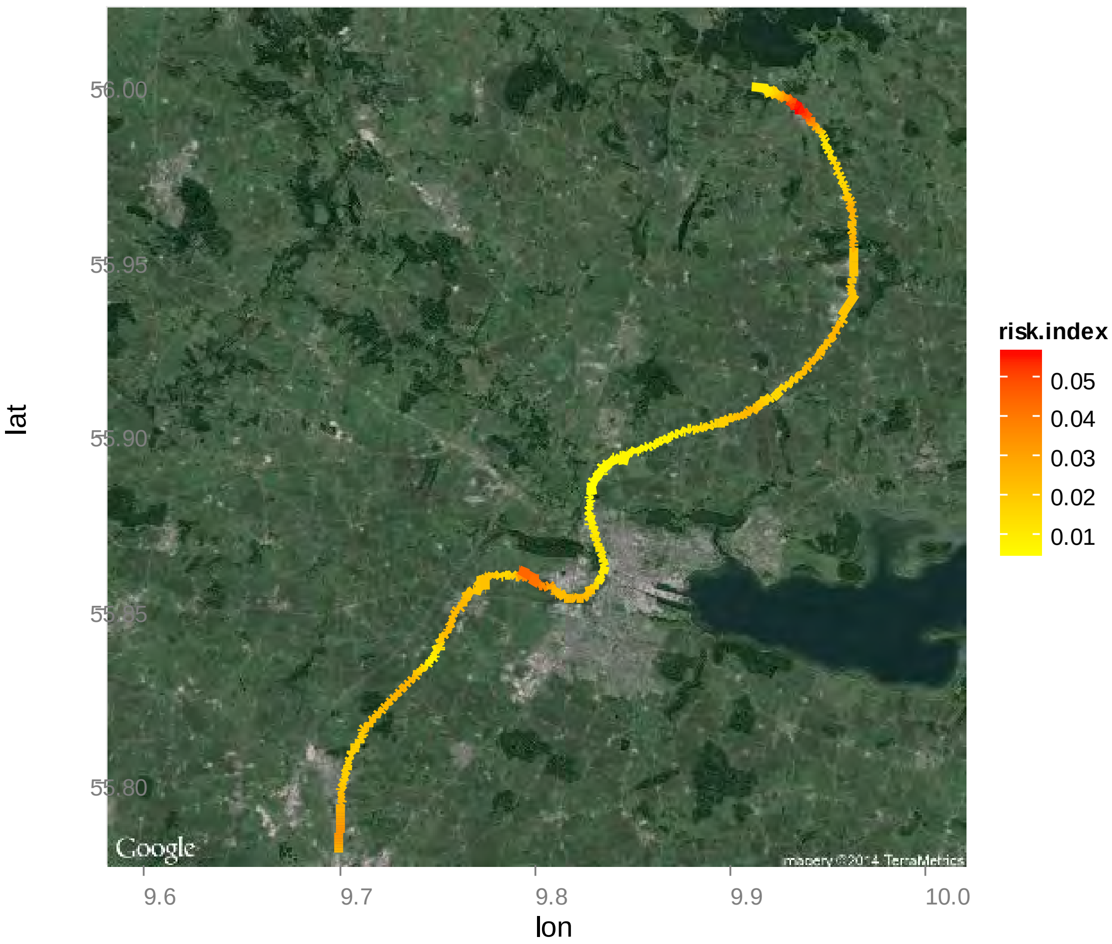
Fuenen map:


55.75
55.50
55.25
55.00
lat
10.0
10.5
11.0
lon
risk.index
0.100
0.075
0.050
0.025
0.000
Google
Imagery ©2014 TerraMetrics

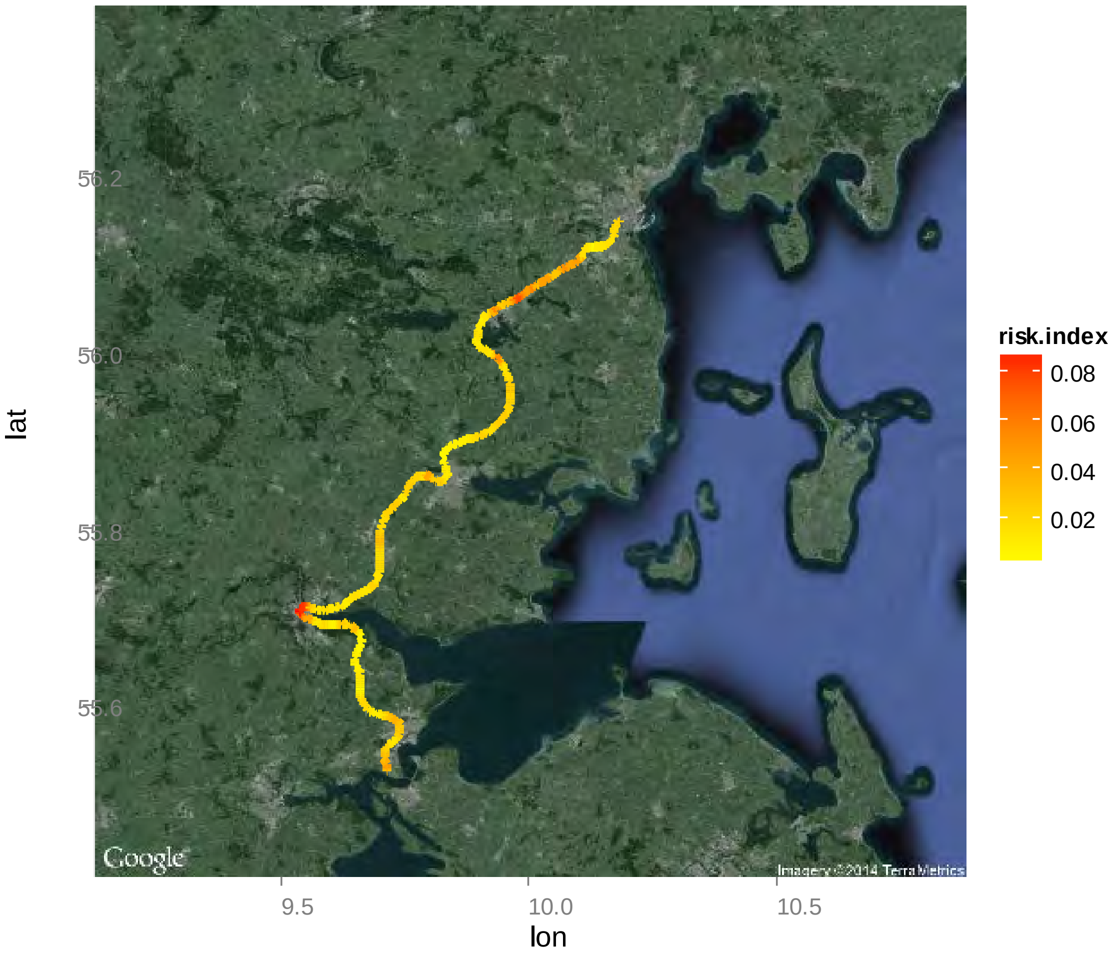
South Jutland map:



Mid Jutland map:



Jutland map:


risk.index
0.08
0.06
0.04
0.02
56.2
56.0
55.8
55.6
lat
9.5
10.0
10.5
lon
Google
Imagery ©2014 TerraMetrics

Management of low adhesion on railway tracks in European countries

Report Commissioned by the Ministry of Transport (Transportministeriet) and Danish State Railways (DSB)

November, 2013

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Contents

Adhesion management in European countries

1 Introduction

This report presents approaches of selected European countries to the management of low adhesion problems. It spans approaches addressing different levels of the problem, including preventive measures focusing on the tasks aimed at removing or reducing low adhesion, mitigative technical measures aimed at improving wheel performance in low adhesion conditions, as well as mitigative measures for driving and operating trains under these conditions. The report thus spans measures that are often managed by different organisations, mainly infrastructure managers and train operators.

The report focuses on management of low adhesion and will not go into detail with the characteristics and generation of the low adhesion layer but will touch on this only to the extent that this determines or is directly linked with the specific low adhesion measures taken. Neither will the report go into detail with purely technical aspects of e.g. braking and WSP systems, but focus on the implied requirements for organisations and drivers.

The report is largely based on literature describing measures taken by existing railway organisations, comprising, besides a few journal article, largely reports by railway organisations and authorities, supplemented by presentations from an International Workshop held at DTU on 16 April 2013 at which experts presented updated knowledge about measures in the UK, Germany, the Netherlands and Sweden

The background for this report was a DTU project originally focusing on a SPAD[1] incident in 2011 in Denmark and the braking ability of a specific type of train (Havarikommissionen 2012), but since expanded to encompass general problems with low adhesion (Nielsen et al. 2012). This report thus addresses problems that are already well-known to Danish railway organisations, but it gathers and analyses results and experiences from neighboring European countries that have similar climate, vegetation and rail infrastructures. This report provides information that is based on up-to-date research and experiments in countries, where this topic has been subject to systematic investigations and empirical research.

1.1 Low adhesion factors

In the following we shall be addressing primarily problems that arise in “very low” adhesion conditions but which also may arise with “low” adhesion. We shall use the term “very low adhesion” to denote an adhesion level below 0.05, sometimes also referred to as “exceptionally low” (AWG 2009). While wheel/rail adhesion is much lower than the adhesion of 0.9 characteristic of road traffic (Rijnaard 2013b), trains normally require 0.1 for braking, and 0.15 or higher for acceleration (AWG 2009).

Very low adhesion is caused by a third layer between rail and wheel. This layer is created by a contaminant or some contaminants which often in combination with light humidity are causing low adhesion. While wet

[1] Signal Passed At Danger.

rails due to for instance rain will also have lower adhesion than dry rails, rain will also tend to clean the tracks of other material (e.g. contaminants). Light humidity, however, combined with leaves in the autumn or other contaminants such as rust or industrial pollution, may create conditions of very low adhesion. Besides contamination and humidity, actual creation of low adhesion also depends on how previously passing trains have compressed and conditioned the third layer and is thus impossible to predict with certainty and precision (Jensen & Klit 2013). Tests carried out in the Netherlands showed how very low adhesion could arise at different locations and then disappear or move within short time (van Steenis 2010).

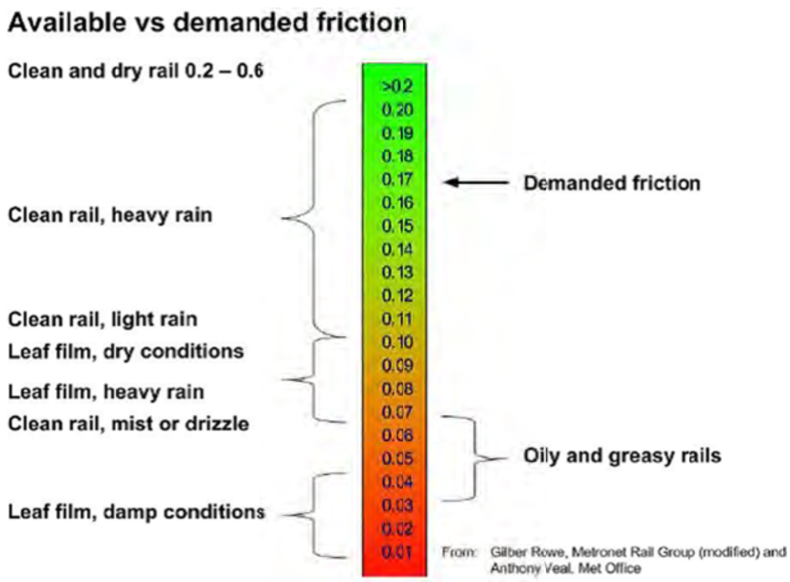


Figure 1 shows different levels of friction (adhesion) compared with the friction required for railway traffic, while describing the characteristics of typical corresponding adhesion layers (Nilsson 2013).

While other factors can reduce adhesion, e.g. oil and grease, the most common problem in Northern Europe and North America is associated with leaves on the line occurring in the autumn season (Spiess 2013).

As previously indicated, the phenomenon is based on a combination of multiple factors making accurate prediction impossible. There are, however, various means for identifying critical areas and times that allow for a useful estimation of enhanced risk based on a number of parameters, as indicated in section 2.1.

1.2 Problems due to low adhesion

Low adhesion creates problems with both spinning and sliding. In the first case, wheels spin on the rail, resulting in problems with traction, causing delays and problems with timetable and regularity, and even damage to tracks. In the second case, wheels slide, leading to problems with deceleration and braking. While spinning is thus a problem of regularity and well-known to drivers and their organisations, slipping leads to station overruns and a direct safety issue in the form of SPADs.

Furthermore, spinning and sliding cause uneven wear and tear on the wheels in the form of wheel flats, in which case rolling stock may be taken out for maintenance, in some cases causing delays and cancellations, thus further problems of regularity; while spinning may damage tracks which also incurs costs for repairs.

1.3 Relevance

While the problem of low adhesion is as old as railway operations, where the basic friction is generally much lower than the corresponding friction for road traffic, various European countries have recently experienced periods with more severe problems (RAIB 2007c;RAIB 2011;Rijnaard 2013b;Voges & Spiess 2006).

A number of trends in modern railway traffic are suspected of aggravating existing problems with low adhesion:

- Modern disc brakes on the axle do not clean the running band of the wheel, as opposed to the older tread brakes.
- Shorter trains have fewer driving bogies and thus more problems with braking (Rijnaard 2013b;RSSB 2004a),
- Modern train sets are lighter and have more problems than older and heavier ones[2] (Rijnaard 2013b).

In addition to existing problems, the European migration to the new ERTMS signaling system is expected to increase the capacity of the railway by shortening the distance between running trains, rendering braking problems due to low adhesion more critical – although also providing additional opportunities for mitigation.

In summary, there are various reasons for improving management of low adhesion. On the one hand, it is a means to improve regularity in the autumn season, both directly by reducing delays due to traction (spinning) problems or sometimes station overruns, and indirectly by minimizing unavailability of rolling stock due to time for repairing wheel flats. On the other hand, it is essential to improve safety by reducing problems with braking and SPADS, although actual investments should be balanced to match the associated risks.

[2] The effect of train weight must be treated with caution, however. The argument was presented at a workshop in Copenhagen 2013, and subsequently specified by Arjan Rijnaard as the vehicle "getting insulated from the railhead due to not penetrating the leaf contamination layer" (Rijnaard 2013a). Yet the physical explanation is ambiguous. Older locomotive-powered rolling stock is heavier than modern trains and not prone to low adhesion (Voges & Spiess 2006), but this may be due to other factors than weight.

2 Different aspects of management of low adhesion

This chapter covers four main aspects of low adhesion management. The first section (2.1) focuses on various approaches to detection, monitoring and even forecasting of low adhesion: information that can be used for various other approaches. The next section (2.2) focuses on *preventive measures* to improve adhesion by track maintenance, generally carried out by infrastructure managers, though sometimes in cooperation with operators. The third section (2.3) focuses on various technical solutions to improve the train's reaction to conditions of low adhesion on the rail, in some cases with implications for human factors and organization – implications beyond the mere technical solution. The final section (2.4) focuses mainly on approaches to support the train driver's ability to cope with low adhesion, as well as a few other operator initiatives.

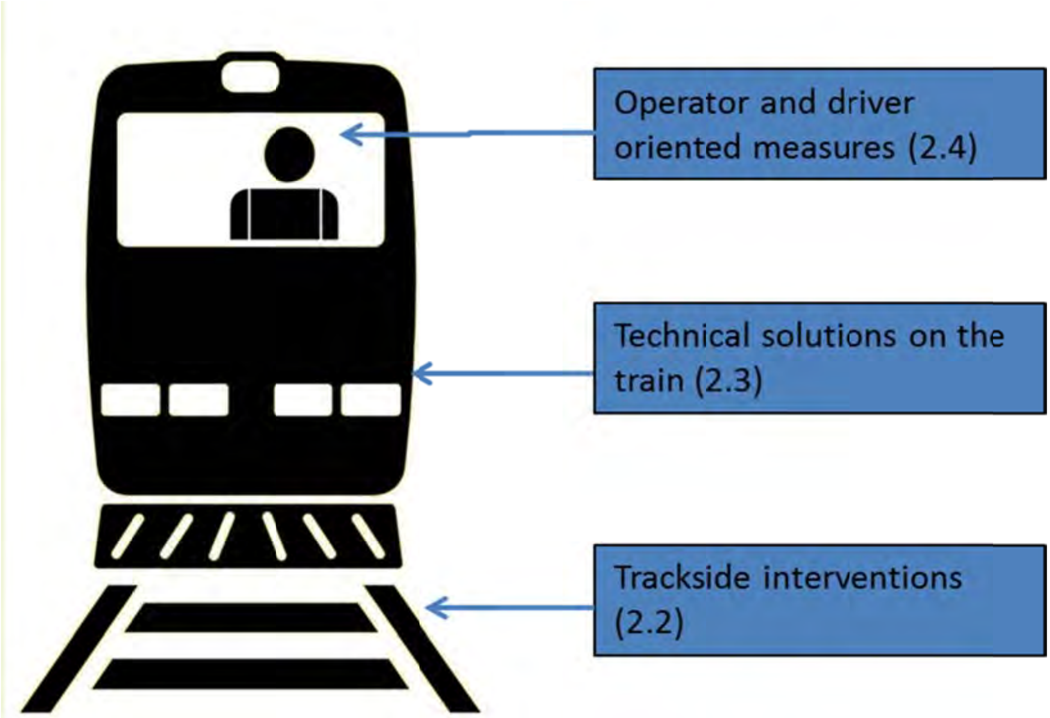


Figure 2 illustrates the orientation of measures described in sections 2.2-4.

2.1 Detection, monitoring, forecast

Before describing various methods employed it is useful to emphasize a distinction between ad hoc detection, more systematic monitoring, and forecasting. Monitoring differs from ad hoc detection by emphasizing a continuous or recurring observation of an area, preferably with the ability to determine both the start and termination of a period of low adhesion for a given area. This may be crucial to prioritize resources towards areas with an actual need, and to limit warnings and cautious driving. Forecasting emphasizes methods for identifying critical areas before they occur, with the option for early interventions and warnings.

Information about low adhesion conditions can be used for various purposes, which will also be described in more detail in later sections. The information can be used for maintenance purposes, typically by an infrastructure manager, to guide interventions towards critical areas, although real-time observations must always be balanced against long-term priorities. For instance, in the Netherlands the infrastructure manager will continuously monitor low adhesion across the country, but will not publish that information, since it might generate a public demand for immediate interventions, in contrast with planned activities based on long-term priorities.

Information about low adhesion can also be used to warn train drivers to take extra care and inform operators to consider possible countermeasures, again with due consideration to avoiding relieving drivers of responsibility for general awareness, and avoiding over-cautious behavior.

Information about adhesion conditions may also be used for adjustments to various technical systems. For instance, older Wheel Spin Protection (WSP) systems take account of low adhesion, but adapt badly to very low adhesion, while newer WSPs may be temporarily adjusted to such conditions – and thus require information about adhesion. Furthermore, Automatic Train Protection systems – e.g. ATC in Denmark – may be adjusted to incorporate more defensive braking curves in critical periods.

In any case, detection and monitoring of adhesion can also be used to simply estimate the criticality of the issue and support decisions about the potential benefit of intervening. Observations could thus also guide decisions not to invest more resources in low adhesion management, if deemed unnecessary.

This chapter will focus on detection techniques for operational purposes and not on methods employed for pure research. With this emphasis in mind, practical implementation of observation should also be designed to observe the dilemma of 'information overload', the risk of gathering more information than can be processed. This dilemma is illustrated by the choice by infrastructure management in The Netherlands not to publish information about low adhesion, which might create a public demand to act on the information.

2.1.1 Methods of detection

Detection methods are generally based on information from trains operated by one operator driving on tracks that are normally managed by another organisation, i.e., the infrastructure manager. Operators use tracks continuously with ample opportunity to experience and observe problems (including low adhesion), whereas the infrastructure manager has limited capacity to survey the lines, and limited access to tracks subject to intensive traffic.

In any case, detection and management of low adhesion are challenged by the fact that such conditions are temporary and thus require frequent monitoring, e.g. to cancel warnings.

2.1.1.1 Reports from drivers

The simplest method of detection is based on drivers reporting when experiencing low adhesion (RSSB 2004b). Such reporting can be either voluntary or mandatory. There are structures for reporting about low adhesion related to incidents that require explanation, both *safety* incidents such as SPADS, but also for regularity issues (delays, station overruns). Drivers may be required to offer explanations for delays, mostly used in negotiations between operator and infrastructure manager, and to provide information for passengers.

In addition to structures for reporting about specific incidents, drivers may also be encouraged to make voluntary reports about very low adhesion, e.g. minor acceleration or braking problems without critical consequences (FTPE 2012). For instance, warning systems in The Netherlands since 2003 (RSSB 2004b) and more recently in Denmark (Banedanmark 2013) have been based partly on driver reports.

Experience indicates that reports from drivers may be biased towards very low adhesion ('negative reporting'), with fewer incentives or opportunities to report about normal adhesion and thus about termination of a period with low adhesion. Reporting about low adhesion may be prompted by actual problems experienced by the driver, while there are no similar occasions for reporting about (return to) normal conditions. Furthermore, the uncertainties of, and incentives for, reporting about 'normal conditions' are ambiguous: normal conditions do not require attention, the *lack* of experience of low adhesion (e.g. no activation of WSP) is a poor guarantee of normal adhesion and the termination of a previously reported critical condition.

In this sense, reporting from drivers is more suited for detection than monitoring, although it may be possible to compensate for the biased reporting by implementing some time limit for reports about critical sites. This was implied in the Low Adhesion Warning System introduced in The Netherlands in 2003, where warnings were sent to driver passing through a critical area within the next two hours (RSSB 2004b).

2.1.1.2 Automatic detection (WSP etc.)

There are various opportunities to estimate adhesion based on data already collected on the train, such as the On-Train Monitoring Recorder (OTMR) or the Wheel Slide Protection (WSP) system. OTMR is similar to the so-called 'black box' recording events in airplanes and has extensive data, but these often have to be downloaded after an event and require interpretation. Modern trains are equipped with WSP systems that register and respond to slide and spin. WSP is controlled by a computer that can gather information about the frequency of these events with a useful indication of adhesion problems. This information, however, is not in itself related to the actual *location* of the train and therefore requires combination with location data, e.g. GPS on train, to identify critical areas with low adhesion.

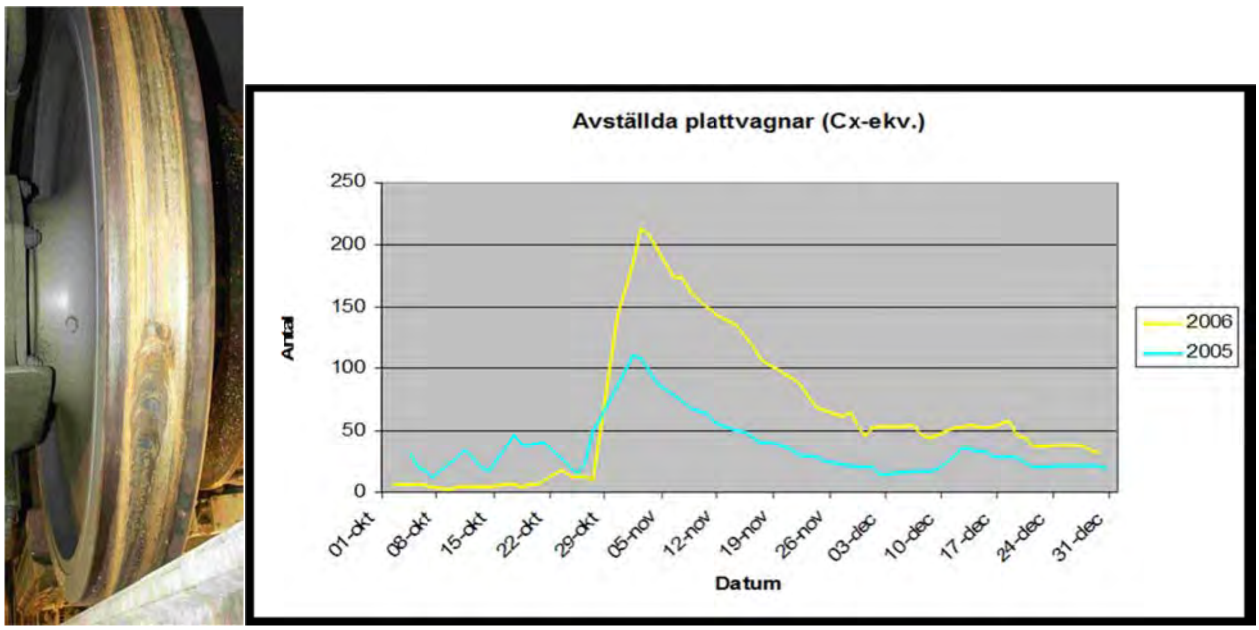


Figure 3. Stockholm Metro uses the number of wheel flats (example left) as a key indicator of autumn performance (right) (Stark 2013).

Automatically collected information via the WSP system, requiring no effort of human drivers, has the potential for providing recurring information about low and higher adhesion (high and low frequencies of slip and spin) and thus for monitoring the conditions of the line, rather than simply *detecting* ad hoc problems. Nevertheless, this method will also offer incomplete results: WSP is only activated during braking, and lack of WSP activation is not a guarantee against low adhesion. A brake action has to occur and the brake force needs to exceed the rail/wheel friction in order for this type of information being available.

However, all methods described so far detect low adhesion during braking (or accelerating) and thus report low adhesion *after the fact*. One challenge is that they only detect adhesion where braking has actually occurred. Another is that detection after the fact is too late to prevent the first incident, in the worst case a SPAD due to sliding. Once a driver experiences sliding, it will often be too late to react, and the situation is 'out of his hands' (e.g. left to the WSP system). While information from WSP is based on numerous non-critical events and thus has the potential to identify critical areas before a dangerous situation actually arises, it would be preferable to get the information earlier, preferably independent of actual braking.

Alternative methods are thus being considered for automatic measuring of low adhesion. One method uses optical sensors to register light reflected from the surface, depending on both topography and material, thus identifying several surface layers (Casselgren et al. 2013;Nilsson 2013). Another method is based on interpretation of general bogie movements, not restricted to braking, and was recently deemed promising by the RSSB (RSSB 2012).

Other methods give general indication of adhesion problems, though again with limited information about actual location. For instance, spinning and sliding cause wear and tear on wheels resulting in wheel flats, and observation of wheel roundness can thus provide information about increasing problems with adhesion (Casselgren et al 2013;Rijnaard 2013b) (see Figure 3).

2.1.1.3 Weather forecast

Besides reporting, registration and observation of low adhesion, there are also some means of prediction, since very low adhesion is often associated with specific weather conditions, and meteorological services already have well-developed methods for weather forecasting.

The problem with leaves on the line is associated with a limited time period in autumn, but it can be difficult to specify more precisely exactly when leaves start to fall. Leaf fall can often be provoked by a strong wind, which can be identified by a weather forecast. On the other hand, a continuous strong wind will also tend to spread the leaves and may thus reduce the problem with low adhesion.

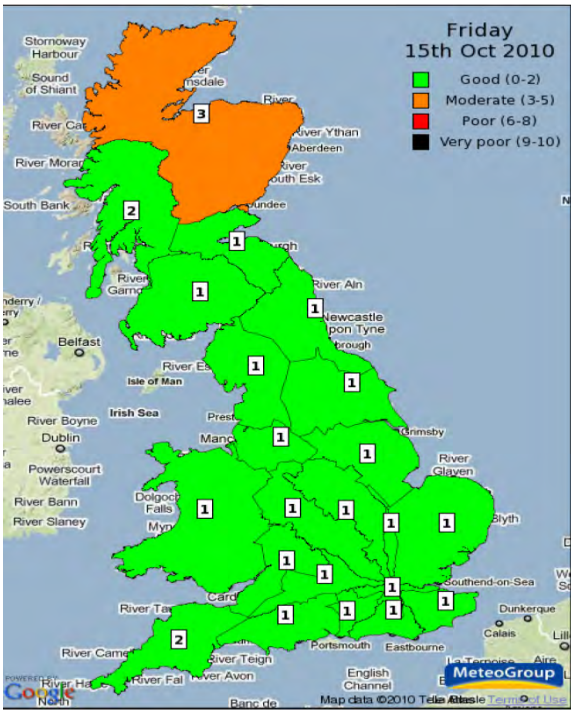


Figure 4. Weather services can provide predictions of adhesion levels, based on weather forecasts and other information. These predictions can be used as warnings for drivers (RAIB 2011) and modification of ATC braking curves (Nilsson 2013). Illustration from (Davidsson 2013).

Humidity is another meteorological cue for low adhesion, which is associated with some moisture, but also reduced by higher humidity, e.g. third layer washed away by rain. Problems may thus be associated with the dew point where air humidity condenses into water (Bridges & Jackson 2013).

Here, too, some combination seems to be highly critical: a period of dry weather followed by slightly humid conditions.

Rail companies, mostly infrastructure managers, in Europe cooperate with meteorological services to establish warning – preferably local – about low adhesion. Such information has the advantage of being preventive, but is also associated with some uncertainty, which poses a challenge to any type of response, e.g. warnings for drivers (2.4.6) or modification of ATC (2.4.7). Many possible responses or interventions are costly, whether based on resources directly invested, or in terms of delays or even reduced services.

2.2 Trackside interventions

Interventions against low adhesion problem may also be made by rail track organisation, typically by the infrastructure manager. Three different methods to improve adhesion are considered here: cleaning of tracks and removing of third layer, long-term management of rail-side vegetation and application of some layer (e.g. sandite[3]) to increase adhesion.

Such procedures are mainly performed by the infrastructure manager who, as mentioned above, has limited possibility of access to the tracks during day traffic, especially on sections (and periods) subject to intensive traffic. Operations such as water jetting and application of sandite are often performed by specialized trains that can only operate effectively at limited speed – at the cost of valuable capacity on the line. Network Rail in the UK has tried solutions with specialized sandite trains running at higher speed (RAIB 2011), whereas Deutsche Bahn in Germany has avoided this solution (Voges & Spiess 2006), and the Netherlands seems to have success in implementing some service (sandite application) on regular commuter trains (Rijnaard 2013b).

2.2.1 Water jetting, removal of third layer

The simplest form of intervention is directed at reducing an already existing problem by removing a third layer, e.g. leaves, and thus cleaning of railhead. This operation is performed by scrubbers and water jets on a low-speed service train, and a main challenge lies in timing the intervention: how to react swiftly to a problem once identified/reported, and with minimal disturbance to traffic. This operation is non-preventive and cannot be planned.

One downside to this operation is that water jets will add humidity to the tracks, sometimes causing problems for the first train after the service, as illustrated in an accident at Berlin (EBA 2008).

There have been experiments with other methods for cleaning the rails and removing the third layer, e.g. use of scrubbers, laser and microwave-generated steam cleaning. However, none were found feasible: scrubbers wear out quickly, and lasers only work at very low speed. While laser and steam were found initially promising, actual implementation would require heavy investments and was deemed unnecessary in comparison with existing methods (RAIB 2007c;RSSB 2002a;RSSB 2008;RSSB 2009).

[3] Sandite is an adhesion modifier consisting of sand, aluminium and a unique type of adhesive, used in the UK, Ireland and the Netherlands. For ease of reading, the term 'sandite' is used in this report as a general name for adhesion modifiers, possibly including similar products.

2.2.2 Long-term management of rail-side vegetation

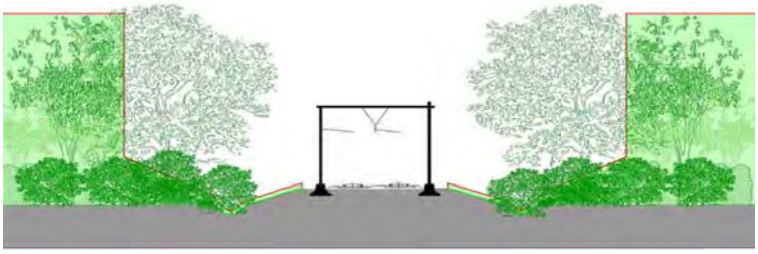


Figure 5. Vegetation management includes cutting of tall vegetation close to the rails and only allow the green areas (left), while full removal of vegetation runs the risk of destabilization at steep slopes (right). Illustration from (Rijnaard 2013b) and (Bridges & Jackson 2013).

More preventive interventions are directed towards the vegetation causing the problem. A drastic method is reduction or direct removal of rail-side vegetation. Full removal bears the risk of destabilizing the ground, especially on slopes on the rail-side (Bridges & Jackson 2013), but more cautious strategies are oriented towards simply limiting tall vegetation closest to the rails (Rijnaard 2013b) – although the very cutting process may temporarily contribute to contamination of rails (FTPE 2012).

Tracks can also be protected from leaves by fences along the line. In the Netherlands, such fences are colored brightly orange and thus also function as a reminder for the driver about local risk of low adhesion (see 2.4.6.1).

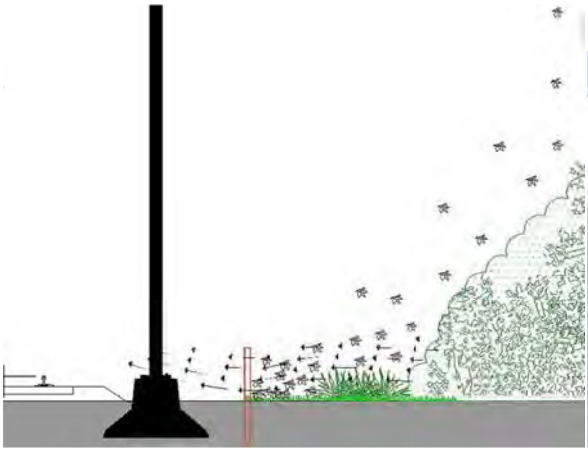


Figure 6. Leaf fences, some with bright colour to warn about adhesion risk. Illustrations from (Rijnaard 2013b).

2.2.3 Friction modification by application of sandite

A different and additional approach is to improve adhesion by applying a layer with high adhesion, mostly some component (e.g. sandite) based on sand and a gel to attach the material to the rail surface.

Sandite etc. can be applied either by hand, by trackside equipment, e.g. before and after platforms (for braking and accelerating) (Rijnaard 2013b), or by a vehicle running on the tracks.

Application by vehicle is hampered by the fact that specialized sanding trains will normally have to operate at a low speed to work efficiently. This may inhibit normal traffic, especially since it must be done frequently in critical periods. The need for frequent application is illustrated by the Stonegate incident in the UK, which occurred one day after the application of sandite (RAIB 2011), and by the decision in the Netherlands to apply it 2-4 times a day in critical periods (Rijnaard 2013b). Application by vehicle was thus rejected by Deutsche Bahn in 2004, because it would interfere with the time schedule (Voges & Spiess 2006). In 2009 Network Rail in the UK started experimenting with a similar product, which could be applied at higher speed, but a serious incident raised doubt about the quality of application at this speed (RAIB 2011).

Nevertheless, operators in the Netherlands now use special installments on commuter trains to apply sandite, either by a separate car or, since 2010, by applications equipped underneath commuter trains (Rijnaard 2013b) (see Figure 7). In this way, sandite can be applied at higher frequency without disturbing the time schedule, and the application is speed regulated to avoid problems with imprecise application (see above). This procedure requires close cooperation between the infrastructure manager responsible for track maintenance and the operator operating the train.

Figure 7. Application of sandite: trackside, by specialized vehicle or from installment on commuter train (in the Netherlands). Illustrations from Internet and (Rijnaard 2013b).

There are other challenges associated with the use of sandite (and sanders on the train, see later). Sand and sandite create a nonconductive layer on the rail and may thus interfere with existing systems to register the location of train, essential to the signaling system and thus to safety (Emery 2011;RAIB 2007c). Sand may also interfere with operation of switches (Spiess 2013).

2.2.4 Other measures by infrastructure management

In addition to these types of track maintenance, other measures can be taken by infrastructure management – measures that are oriented towards operation.

Infrastructure management can thus impose speed restriction for critical areas to minimize the risk of excessive braking distances and SPADs. By itself, however, such a measure may aggravate problems for a driver trying to keep the schedule (Scholdan 2013), and for the operator.

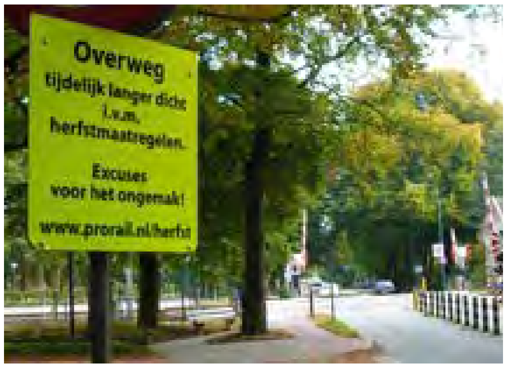


Figure 8. This sign warns Dutch car drivers about preventive closing of a level crossing behind a platform for early morning trains (Rijnaard 2013b).

Another measure is taken by the infrastructure manager in the Netherlands: preventive closing of level crossings behind a platform for early morning trains (Rijnaard 2013b), to protect car traffic from trains overrunning the station (see Figure 8). This measure has the additional effect of signaling caution and awareness of low adhesion issues to the public.

2.3 Technical solutions on the train

In contrast to the track-side measures described in 2.2, we now review a number of train-side interventions that are available to guiding or improving train performance. This section focuses on purely technical solutions on the train available to the operator, while also emphasizing possible human and organizational implications for driver and operator. These solutions are thus often not simple technical solutions that improve braking (or accelerating) independently of human or organizational factors, but will typically require some management and operational activities.

2.3.1 Sanders

With this solution, almost as old as the railways, the train is equipped with containers of sand that can be applied – by the driver or automatically – to improve adhesion, whether for braking or accelerating. Sanders are used and considered indispensable in many European countries, including the UK and Germany, but avoided by others due to a number of challenges.

There are challenges with maintenance and application of sand. The amount of sand in the containers must be sufficient to be available for critical situations, and two critical SPADS in the UK suffered from lack of sand (RAIB 2007b;RAIB 2011). It is therefore essential to have proper procedures for maintenance and refilling of sand containers, and this requirement has been considered unfeasible in the Netherlands where trains are not kept in depot overnight due to intensive use (Rijnaard 2013b).

A related challenge is the proper – timely and adequate – application of sand, which can either be deliberate (by the driver) or automatic, typically linked to a specific braking level. The criticality of timing is illustrated by a SPAD incident at Esher in the UK (RAIB 2007a), which was worsened by the late – automatic – dispensing of sand. But dispensing of sand can also be too early and too 'generous', which will require frequent refilling and may also lead to problems with excessive amounts of sand on the line (see below).

The efficiency of sanding will also depend on the speed of the train. Old systems operate independently of train speed and thus vary much with speed, dispensing relatively large amounts (piles of sand) at low or no speed while spreading the same amount imprecisely on larger areas at high speed – in which case the sand is simply blown away, with no effect on adhesion. These problems have led to doubts about the efficiency of sanding for high speed trains, but have been improved in newer systems where dispensing is speed regulated (Rijnaard 2013b;Spiess 2013) and controlled by high pressure jets.

Besides problems with the efficiency of sanding, sand may also create problems for the railway, as already mentioned in relation to sandite. Sand may interfere with existing systems for registration of trains and the track occupancy so critical to the signaling system (Emery 2011;RSSB 2002b). And excessive amounts of sand may disturb the operation of points – a problem that may be reduced by a more accurate application of sand, avoiding areas close to vulnerable installations.

2.3.2 WSP

Modern trains are equipped with Wheel Slide Protection systems, a technology used in the railway for several decades and similar to the more recent ABS system for cars. The system automatically detects when wheels are sliding during braking and reacts by releasing and reapplying brakes to achieve better effect. This operation relies on a registration of actual train speed, preferably independent of wheels subject to low adhesion.

One challenge with WSP is thus the proper observation of train speed. If this observation is based on sliding wheels, the WSP will believe that the train is actually slowing and sees no need to release and reapply the brakes.

A number of incidents have revealed that first-generation WSP systems, while operating with acceptable efficiency at low adhesion, are less efficient at very low adhesion and have actually been “one of the causes for the unusual overshooting of breaking distances on rails subject to autumnal conditions” (Hase et al. 2005) .

As a solution to this problem, newer generations of WSPs have implemented different adhesion modes, allowing users to select a special mode with adjusted parameters for conditions of very low adhesion. This solution requires operators to install a new WSP or at least implement a software update (Rijnaard), but it also requires relatively detailed information about adhesion conditions in order to ‘fine-tune’ the WSP.

2.3.3 Magnetic track brakes (MTB)

Magnetic Track Brakes operate by direct contact with the rails, hence independently of rail/wheel contact. They still depend on contact with rails and are therefore affected by low adhesion due to a third layer, but will also have some effect of cleaning the rails of such contamination – although UK experience found such an effect to be very limited (RSSB 2002b). The magnetic brake is pressed on the rails by magnetic force, thus the friction force is independent of the weight of the train.

Figure 9. Magnetic Track Brake (in red).

MTBs can have a negative effects on track circuits and thus interfere with detection of track occupancy and signaling systems and have for this reason been avoided in the UK (RSSB 2002b), while they are regarded as indispensable safety measure in other countries (Rijnaard 2013b;Spiess 2013;Voges & Spiess 2006).

MTBs are heavy compared to newer and lighter train sets and are generally only used occasionally for emergency braking to minimize wear due to contact with rails and generation of heat (Emery 2011;RSSB 2002b). Drivers may be tempted to use the MTBs more frequently, at the risk of reducing their efficiency in emergency situations (RSSB 2002b).

2.3.4 Eddy Current brakes

These brakes use magnetic fields that induce electrical eddy currents in the rail head that in turn produce a resisting force on the moving magnets. The brake's magnets are not in contact with the rail head, there is a small air gap of a few millimeters. Eddy current brakes thus have the advantage over the MTBs of being independent of existing adhesion.

However, they are also heavy, tend to generate heat, are less efficient at low speed and suspected of interfering with track circuits (Emery 2011;RSSB 2002b).

2.4 Operator and driver-oriented approaches

Various measures are taken by train operators to cope with low adhesion, besides the technical equipment of trains. Several measures are oriented towards supporting and guiding the train drivers in their attempt to cope with low adhesion conditions, while a few measures are independent of train drivers. The latter are presented first.

2.4.1 General operator initiatives

Since some types of rolling stock (lighter and shorter) are more sensitive to low adhesion, train operators can reduce problems by using more 'adhesion robust' train sets – longer and heavier – in critical periods. In UK, shorter train sets are thus combined to "reduce slip risk" during autumn (RSSB 2003).

Other operator measures focus on timely maintenance of train axles and wheels exposed to increased wear resulting in wheel flats (Nilsson 2013;Rijnaard 2013b).

2.4.2 Driving techniques

Operator initiatives oriented towards the driver must take their starting point in the driver's confrontation with low adhesion.

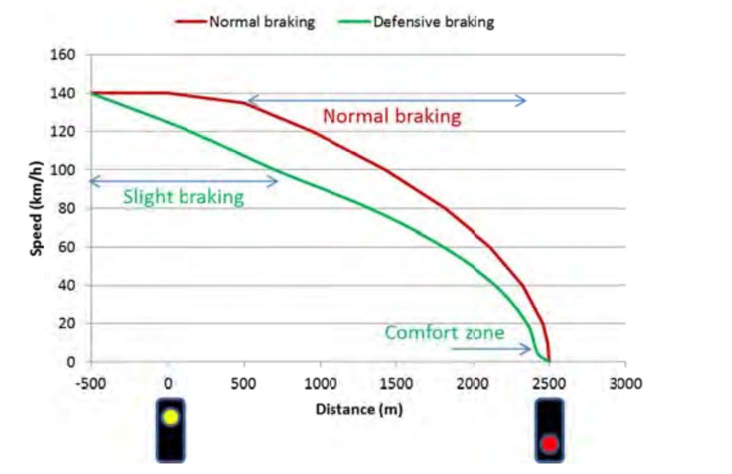


Figure 10. Defensive driving requires earlier braking (green), in contrast with a steeper braking curve characteristic of a non-defensive approach (red).

The basic technique in coping with low adhesion is so-called 'defensive driving': to brake earlier and lighter (see Figure 10). The driver starts braking earlier than under normal conditions, starting with limited brake power (a low brake level). The second element of this technique (light braking) has been slightly modified based on experience from SPAD incidents, the driver now having to start using a somewhat higher brake power. One reason for braking harder from the beginning is to make better use of spots with higher adhesion when available (RAIB 2007c).

In addition to the regular brakes, the driver can also make use of additional systems such as sanding and MTB. Sand can be used deliberately by the driver or released automatically, in which case the driver still needs to be aware of the use. The driver can react to signs/cues of low adhesion and activate additional systems.

In the UK, sanding is linked automatically to the WSP, but not at the lowest brake level – in order to limit the use of sand, to avoid emptying of containers and limit unwanted consequences on the rails (wear and tear, track circuit problems). However, this limitation leads to ambiguous feedback to the driver, who must know *when* to release, or whether sand has been released automatically. There is only one lamp for WSP activity, which the driver normally also associates with sanding – which would be a misconception at the lowest brake level.

Some of these driving techniques are highly dependent on specific technical designs (brake levels, sanding, WSP indicators), but the general point to emphasize is that the driver needs feedback about low adhesion during braking (WSP indicators), and means for activating additional systems (e.g. MTB, sanding) when necessary, but not excessively – and/or to confirm the activation of such systems.

Besides the above emphasis on the drawbacks of the additional systems and the need to limit their use, the very technique of defensive driving also has the disadvantage of being slower than normal braking behavior and thus causing delays. This leads to problems with timetable and passengers and may even press other drivers to drive – and brake – more aggressively, with the increased likelihood of SPADs and station over-runs. These problems lead to concerns of drivers being over-cautious (van Steenis 2010), one infrastructure manager even arguing that “*"defensive driving" by new drivers was aggravating the problem*” (Clark 2003), thus emphasizing the need to limit the use of defensive driving to situations where it is necessary, while avoiding it under normal conditions. This again emphasizes the drivers’ need to have clear indication and cues about when to use defensive driving techniques.

While the drivers should thus avoid overcautious driving, they also depend on early cues and previous knowledge of critical sections to act as early as possible – since they will often be ‘powerless’ once on a section with very low adhesion.

Critical cues available to the driver are thus; knowledge of critical sections with a higher risk of low adhesion; critical weather conditions (low moisture, possibly following a longer dry period); driving the first train in the morning or on a line with little traffic or as the first train after the cleaning train (FTPE 2012).

Besides these cues, the driver’s reaction will also be based on other information, some of which may be ambiguous.

One such example is the driver’s expectation of braking effect. Drivers will thus base their braking approach on experience with the train’s braking power. They will often have learned, during dry periods in the summer, to expect very high effect when increasing the brake power. However, this experience and expectation can be misleading during periods with low adhesion (Scholdan 2013;Spiess 2005).

Other examples of ambiguous information available to drivers are (depending on technology): WSP indicators and its connection to sanding (as already mentioned); a speedometer based on movement of wheels and thus vulnerable to low adhesion; information about available brake power (Spiess 2005).

2.4.3 Training of drivers

There are different ways for an operator to guide train drivers towards optimal behavior when facing low adhesion. One way is to provide training to teach drivers awareness about cues and the proper braking technique (see above). Train driving is a highly practical profession, and training will often emphasize practical experience. The typical education of train drivers includes a period of actual driving with an instructor, but it is difficult to ensure experience with low adhesion, especially outside the autumn season. Such experience can be provided by other means, e.g. in the form of "*computer-based awareness and instructional training*" (Voges & Spiess 2006), such as driving cab simulators (see Figure 11), or the use of separate sections with artificially modified low adhesion, so-called 'skid pan training' (AWG 2009;Mann 2013).

Figure 11. Driving cab simulator. Illustration from (AWG 2009).

In any case, practical training will have to be adapted to different types of trains.

2.4.4 Instructions, driving policies etc.

Defensive driving techniques can also be implemented by the operator as a *driving policy*, requiring the driver to drive – and brake – in a specific way, rather than relying on the driver's own professional expertise and judgment. Driving differently would then be judged as non-compliance, with possible repercussions for the driver.

The use of driving policies varies among the European countries, such a policy playing a crucial role in a number of adhesion incidents in the UK autumn 2005 and treated as an instrument for improvement and organizational learning, while largely avoided in Denmark.

It may be asked, why have a driving policy and not simply rely on the driver's professional judgment – as it is surely in the driver's own interest to avoid accidents? One advantage of a policy would be to guard against reckless driving, while another might be to protect the driver – and safety – in possible conflicts between safety and time schedule. The driver will always be encouraged to drive on time and to catch up with delays – and may be questioned about such delays, but a driving policy will defend the use of defensive driving.

There are also drawbacks, however. The technique canonized as driving policy may be fallible and not fit every conceivable situation, or they may not be updated with recent developments. For instance, it may be difficult to specify the meaning of 'braking light', when some trains have only three steps, other have several, and some trains use variable braking force. In some situations, a driving policy may prevent the driver from using skills to make a professional judgment leading to another and perhaps safer approach. In Denmark, the driver's trade union was against a specific 'autumn instruction', arguing that it draws attention away from low adhesion outside the autumn season (Østergaard 2012).

In the UK, there are no policies issued by the RSSB, but a guidance note (ATOC 2003) by the Association of Train Operating Companies (ATOC), which has been implemented as driving policy by several operators. As previously indicated, this policy instructed drivers to brake 'light and early' in case of low adhesion, where 'light' was generally interpreted as 'step 1'[4].

As already indicated, this driving policy was examined as one of the contributing factors for several incidents, since 'step 1' does not release sand and probably makes insufficient of possible sections with higher adhesion. The driving policy was thus modified by several operators after the autumn 2005 incidents (RAIB 2007c).

A more recent incident, however, illustrates that this policy – and technique – depends on the availability of sand – the release of sand being one of the reasons for going directly to brake step 2 (see previously). At Stonegate, the driver during the incident followed the policy using step 2, and proceeding to step 3 and then applying the emergency brake after experiencing insufficient deceleration. He later – after the incident – used the outdated procedure of braking lightly and early, with better effect, but then reverted to the official policy to avoid critique for non-compliance. Evidence showed that the train was out of sand, eliminating one advantage of brake step 2, and that the subsequent increase of brake power actually resulted in slower deceleration (RAIB 2011). The incident illustrates the – counter-intuitive – inefficiency of braking harder than the adhesion available, a challenge normally controlled by the WSP system. The driving policy depends on the availability of sand and should allow for a different approach, should sand be lacking. The operator has thus revised the driving policy, which no longer requires mandatory use of brake step two.

2.4.5 Autumn schedule etc.

Low adhesion during autumn increases the risk of delays, both due to defensive driving, speed restrictions and problems with acceleration. This leaves drivers with an increased pressure to catch up with delays, and thus to drive – and brake – more aggressively. The drivers are thus faced with an even greater conflict between the general requirement to keep the schedule and the passengers happy, and the need to drive safely.

Various measures can be taken to relieve the driver of this pressure and/or take account of the actual delays caused by autumn conditions. A mild measure is used in the Netherlands to gain more driving time between stations by having shorter stops at station platforms (Rijnaard 2013b). This solution seems to presuppose that normal seasons leave ample time for entering and exiting at station platforms and may require extra staff on platforms to assist e.g. elderly and disabled passengers.

A stronger measure is to take account for delays by having a separate schedule for the autumn season (Emery 2011), e.g. in UK (Clark 2003). This solution represents numerous challenges to operators and infrastructure management. There will be fewer trains in autumn and overall reduced capacity for passengers, passenger confusion due to changes in schedule, and huge challenges with

Figure 12. Special timetable for autumn season. Example from (AWG 2009).

[4] This policy is based on a braking system with three steps + emergency brake, where step 1 is analogous to a braking rate of 0.3 m/s^2, step 2 to 0.6 m/s^2 and step 3 to 0.9 m/s^2 (RAIB 2007c).

interconnections between different lines and different operators.

Therefore, most countries struggle with alternative solutions to avoid a specific autumn schedule, as emphasized in both Germany and the Netherlands (Spiess 2006;van Steenis 2010).

2.4.6 Warnings

Drivers can be supported by warnings about low adhesion conditions, based on various types of information (see section 2.1).

2.4.6.1 Static, site-based warning

One type of warning informs the driver about specific areas with a known risk of low adhesion, based on rail-side conditions (e.g. vegetation) or history of incidents. This information supplements the driver's own knowledge of the line – knowledge generally required for train drivers. The driver must then use additional information, e.g. weather condition and previous weather, to estimate the current – time-based – risk of low adhesion and show proper precaution.

This information can be provided by signs along the track, or by colorful fences that serve both to protect the track from leaves, *and* to warn the drivers about the presence of such leaves. There are some ambiguous aspects of such signs, however. On the one hand, they seem to exempt the drivers from reporting further problems, which might otherwise inspire the infrastructure manager to introduce speed limits (Emery 2011). Some operators thus encourage their drivers to report serious conditions of very low adhesion for areas already marked as critical (FTPE 2012). On the other hand, the associated or implied sign of 'end of low adhesion' may create a false impression of 'good adhesion' and cause an untimely relief of driver vigilance, since adhesion does not always obey to signs (Emery 2011).

2.4.6.2 Time-specific warnings

Another type of warning informs the driver of specific 'local'/'current' areas with low adhesion based on updated information. One such example was previously used in the Netherlands, where a measurement or a driver report initiates a 2 hour period of 'low adhesion' for that particular area, during all drivers passing through the same area are warned by a text message (SMS) alert by the Region controller (RSSB 2004b).

2.4.6.3 Forecast based on weather

A third type of warning is predictive and based on weather forecast. One such example is used in the UK and illustrated in the investigation of the Stonegate incident. The infrastructure manager provides a forecast indexing the risk of low adhesion conditions on a scale from '1' ('Good') to '10' ('Bad'), where '9' or '10' "*indicates a 'black' day, corresponding to 'extreme leaf fall contamination' being expected*". The driver receives this information when booking on a station, by reading a notice (RAIB 2011).

The use of weather forecasts has the advantage of being predictive, but with considerable uncertainty. According to a recent Dutch study, "[t]he existing model for predicting low adhesion … is not good enough to warn drivers with a great level of reliability or to use the warning to take certain measures" (van Steenis 2010).

An older RSSB report emphasizes the need for warnings "to be appropriately localised so as not to impact unnecessarily on train performance" (RSSB 2004b), illustrating the need for a proper combination of site specificity (see section '2.4.6.1') and actuality.

2.4.7 ATC and similar

Parameters in Automatic Train Protection systems, e.g. ATC in Denmark, can be adjusted to implement flatter braking curves and longer braking distances. This will let the automatic system start braking earlier than otherwise, indirectly instructing drivers to brake earlier to stay within the allowed braking curve, thus encouraging automatically towards 'defensive driving'.

While the ATC system is a technology installed on the train, yet coupled to the signaling system, the adjustment of ATC parameters is an operation performed by the driver or by the operator. This adjustment is thus a human or organizational operation rather than a merely technical solution.

Adjustment of ATC braking curves depends on information about low adhesion and may be difficult to adapt to actual conditions that are difficult to predict and monitor, especially when 'low adhesion parameters' should only operate when necessary and thus be cancelled when the problem disappears. It may be easier to use these parameters for a longer, fixed period, typically in autumn – at the risk of not matching actual conditions of low adhesion or operating with lower efficiency (longer braking distances with less extensive use of railway capacity, e.g. fewer trains).

This approach, a combination of an estimation of adhesion and selection of braking curves in the ATC is implemented in a metro line within Stockholm Public Transport. A prediction of adhesion level (levels 1-3) is generated based on weather forecasts, traffic and work with possible contamination, and this prediction is then used, among other suggestions, to select among three different brake modes with different brake curves (Nilsson 2013).

3 Approaches in selected European countries

Various European countries have recently experienced periods with severe problems of low adhesion (RAIB 2007c;RAIB 2011;Rijnaard 2013b;Voges & Spiess 2006) and have arrived at different approaches to adhesion management, reflecting different national 'paradigms' with particular combinations of measures. Comparing Germany with the Netherlands, in particular, illustrates how some measures depend on specific conditions, while excluding other measures.

Germany reacted to an alarming number of problems during autumn 2003 by mitigative measures focused on improving the performance of rolling stock in conditions of low adhesion. The German solution is thus a combination of sanders, magnetic track brakes and an update of the WSP systems. Use of sandite or similar was considered, but deemed unfeasible due to the interference of the special sandite service trains with regular traffic.

In the Netherlands, however, a different combination was selected. While using MTB, sanding on the trains - as used in both Germany and the UK - was deemed unfeasible, since the rolling stock is used extensively and is not kept in depots during night, and thus with no opportunity of reliable refilling of sand. Instead, the solution focuses on preventive measures for improving adhesion by frequent application of sandite. The challenge from gaining adequate access for frequent application, 2-4 times a day in critical periods, is minimized by installing equipment on regular trains instead of using specialized vehicles that interfere with regular traffic. By this approach, track interventions - infrastructure management - are performed by regular trains run by an operator - and thus require close cooperation between operator and infrastructure manager.

This approach illustrates the cross-organisational challenge from low adhesion that concerns different railway organizations. This challenge is also illustrated by the fact that the Adhesion Working Group in the UK was created after the dissolution of British Rail in view of the need for coordination across rail/wheels organization. The AWG has carried out several research projects on different aspects of adhesion and also has members from other countries.

4 Summary

This report has presented a variety of measures to manage low adhesion problems, most already in use or at least subject to experiment in European countries. The measures described include methods for detection and monitoring, preventive measures for trackside intervention and mitigative measures in the form of technical solutions on the train and organizational measures oriented towards the driver.

- **Detection and monitoring**
  - Reports from drivers
  - Automatic detection (WSP or other)
  - Prediction based on weather forecast
- **Preventive trackside interventions (by infrastructure manager)**
  - Removal of third layer – by water jetting etc.
  - Long-term management of trackside vegetation
  - Improving adhesion by application of sandite or similar
- **Technical solutions on the train**
  - Sanders
  - Wheel Slide Protection (WSP)
  - Magnetic Track Brakes
  - Eddy current brakes
- **Operator and driver-oriented measures**
  - Training of drivers (with emphasis on practical experience)
  - Instructions, driving policies
  - Autumn schedule
  - Warnings for drivers
  - Modification of ATC (based on predictions)

As we have seen, the approaches used in other countries are to apply a combination of several measures. It would be convenient if the problem could be eliminated 'from the bottom up', but the phenomenon is too unpredictable for reliable preventive measures for timely removal of low adhesion layers by infrastructure management.

While there are several technical solutions to improve the performance of trains under low adhesion, none of these is adequate to achieve fully reliable performance (e.g. independent of driver vigilance). Furthermore, many technical solutions tend to require organisational management, e.g. for refilling of sanders and adjustment of WSP parameters depending on adhesion conditions - especially for very low adhesion.

Therefore, the performance under low and very low adhesion will still depend on driver vigilance and skills for reasonably cautious estimation of adhesion conditions and appropriate driving measures. These may again be supported by organisational measures for training appropriately for low adhesion, providing appropriate warnings and perhaps reducing pressure from timetable in critical periods.

Comparison among European countries also illustrates that there are constraints on various measures that cannot be combined freely. For instance, the use of sanders on trains depends on reliable processes and facilities for refilling, and sandite preparation requires a reliable method for timely application with minimal disturbance to normal traffic – possibly with coordination between train operators and infrastructure management.

5 Conclusion

Nearly all of the measures presented in this report will require coordination between the infrastructure manager and the railway operators, an interface which is now common to European countries. For instance, if the infrastructure manager runs a track cleaning train, leaving the tracks somewhat moist, the operator must know that the first regular train following this will have slightly degraded braking performance. Given the need for coordination, it is therefore likely to be more efficient to spell out a national strategy that defines, first of all, the risk control measures to be applied as well as their practical implementation and coordination, and that, as a second step, allocates responsibilities to individual stakeholders. This approach should be based on the recognition that the problems raised by low adhesion are challenges that are *shared* across organizational borders. Therefore, to focus on separate measures available to individual organisations may invite each of the parties to optimize within their own domain rather than collaborate on coordinating responses to shared challenges.

Selection and allocation of measures should be based on due consideration of both the risk associated with low adhesion and the cost and effect of measures. A recent report by the Danish infrastructure manager and the Danish Transport Authority (Trafikstyrelsen & Banedanmark 2012) has been able to identify only a few adhesion-related incidents, leading to an estimate that the risk is limited and existing measures adequate.

While existing evidence thus indicates that worries over low adhesion in Denmark should not be exaggerated, it may also be worth keeping in mind that the future calls for a more intensive use of railway capacity in Europe with shorter distance between trains and a more extensive use of highspeed trains, notably with the new signaling system, ERTMS. Furthermore, a better management of low adhesion not only serves as a defense against the risk of incidents, but may also serve to minimize losses from wear and tear as well as delays and associated public discontent.

6 Appendix: Table overview of measures

Type	Title	Chapter	Advantages	Challenges
Detection	Reporting	2.1.1.1	• Based on actual experience with low adhesion	• Biased towards 'negative reporting' of very low adhesion, not restoring of adequate adhesion
	Automatic detection	2.1.1.2	• Independent of driver alertness • Systematic monitoring	• Available data difficult to process
	Weather forecast	2.1.1.3	• Supports early warnings for drivers and infrastructure management	• Considerable uncertainty
Track maintenance	Water jets etc.	2.2.1	• Removes adhesion layers	• Lower adhesion for first train • Reactive: response to actual leaf fall etc.
	Vegetation management	2.2.2	• Preventive measure to minimize contamination	• Requires resources • Removal may create other problems
	Sandite etc.	2.2.3	• Preventive measure to improve adhesion	• Normally applied at low speed • Interference with regular traffic • Possible interference with track circuit • Possible interference with switches
Technology on trains	Sanding	2.3.1	• Instant improvement of adhesion	• Difficult at high speed • Possible interference with track circuit • Possible interference with switches • Requires reliable processes for refilling • Requires driver awareness of availability and activity
	WSP	2.3.2	• Indispensable	• Must be modified for very low adhesion
	Magnetic Track Brakes	2.3.3	• Clean the rail-head • Independent of wheel surface	• Heavy • Wear and tear • Only limited cleaning of railhead • Only for emergency • Only at high speed • Adhesion-dependent – contact with rails • May interfere with track circuit
	Eddy Current brakes	2.3.4	• Adhesion-independent	• Heavy • Only at high speed • May interfere with track circuit
Operator and driver-oriented	Driving policy etc.	2.4.4	• Clear instructions for inexperienced drivers • Instrument for organizational learning	• Difficult to adapt to specific equipment • May interfere with driver skill and vigilance
	Autumn schedule	2.4.5	• Relieves pressure on driver	• Reduces railway capacity
	Warnings for drivers	2.4.6	• Support driver alertness in critical periods and locations	• Difficult to time appropriately
	ATC	2.4.7	• Independent of driver vigilance and experience	• Difficult to time appropriately

7 References

Note on references: Presentations made at the International Workshop 16th April, 2013 at DTU including supplementary material are available at: http://s1.spm.man.dtu.dk/low-adhesion/
User name: low; Password: adhesion

ATOC 2003, *ATOC Guidance Note - Defensive Driving Techniques*, Association of Train Operating Companies, ATOC/GN007.

AWG 2009, *Managing low adhesion*, Adhesion Working Group, 4th edition.

Banedanmark 2013, *Evaluering af trafikmeddelelse 34/2012* København.

Bridges, J. & Jackson, T. 2013, "Managing the GB Rail Network During Autumn", Presentation at Low Adhesion Workshop, DTU. 16/4/13

Casselgren, J., Olofsson, U., Zhu, Y., Löfving, S., Mayer, L., & Nilsson, R. 2013, "An optical sensor for the identification of low adhesion in the wheel-rail contact", *International Journal of Railway Technology*, vol. 2.

Clark, A.2003 Cautious drivers 'add to leaves woe' on rail lines. The Guardian . 2003. http://www.guardian.co.uk/uk/2003/oct/21/transport.world

Davidsson, R. 2013, "Rail weather services", Presentation at Low Adhesion Workshop, DTU. 16/4/13

EBA 2008, *Zusammenstoß Bahnhof Berlin - Südkreuz 20.11.2006*, Bundesministerium für Verkehr, Bau und Stadtentwicklung, Eisenbahn-Unfalluntersuchungsstelle des Bundes, Bonn.

Emery, D. 2011, "Magnetic Brakes to avoid SPADs due to poor adhesion conditions", Swiss Transport Research Conference, Monte Vérita.

FTPE 2012, *Professional Driving Policy and Guidance*, First TransPennine Express.

Hase, K.-R., Müther, S., & Spiess, P. 2005, "Neue Erkenntnisse zum Gleitschutzverhalten elektrischer Triebzüge", *ETR: Eisenbahntechnische Rundschau*, vol. 54, pp. 599-610.

Havarikommissionen 2012, *IC4-togsæt passeret signal i "stop" ved Marslev den 7. november 2011*.

Jensen, N. S. & Klit, P. 2013, *Study of Friction between Wheel and Track*.

Mann, D. 2013, "Driver-oriented approaches to low adhesion - a GB Rail perspective", Presentation at Low Adhesion Workshop, DTU. 16/4/13

Nielsen, N. A., Kjær Ersbøll, B., Petersen, A. S., & et al 2012, *Undersøgelse af IC4-togets bremseevne – midtvejsrapport*.

Nilsson, R. 2013, "Practical experiences and research in the area of low adhesion at Stockholm Public Transport", Presentation at Low Adhesion Workshop, DTU. 16/4/13

Østergaard, N.2012 Lokoførere: Nye bremsekrav på glatte skinner er hul i hovedet. Ingeniøren . 2012. http://ing.dk/artikel/130714-lokofoerere-nye-bremsekrav-paa-glatte-skinner-er-hul-i-hovedet?utm_medium=email&utm_source=nyhedsbrev&utm_campaign=ingformiddag

RAIB 2007a, *Autumn Adhesion Investigation Part 1: Signals WK338 and WK336 Passed at Danger at Esher*, Rail Accident Investigation Branch, Department for Transport, 25 (Part 1)/2006.

RAIB 2007b, *Autumn Adhesion Investigation Part 2: Signal LW9 Passed at Danger at Lewes 30 November 2005*, Rail Accident Investigation Branch, Department for Transport, 25 (Part 2)/2006.

RAIB 2007c, *Autumn Adhesion Investigation Part 3: Review of adhesion-related incidents Autumn 2005*, Rail Accident Investigation Branch, Department for Transport, 25 (Part 3)/2006.

RAIB 2011, *Station overrun at Stonegate, East Sussex, 8 November 2010*, Rail Accident Investigation Branch, Department for Transport, Derby UK, 18/2011.

Rijnaard, A. 2013b, "Low adhesion management in the Netherlands", Presentation at Low Adhesion Workshop, DTU.

Rijnaard, A.2013a Re: Problems with lighter stock - Email. 2013a.

RSSB 2002a, *Laboratory and on-track testing of Laserthor railhead cleaner*, Rail Safety and Standards Board, T144.

RSSB 2002b, *Overview of magnetic brakes*, Rail Safety and Standards Board, T060.

RSSB 2003, *ERTMS adhesion management: Review of ATP, ATO and ERTMS*, Rail Safety and Standards Board, T080.

RSSB 2004a, *ERTMS adhesion management: An overview of low adhesion factors for ERTMS*, Rail Safety and Standards Board, T080.

RSSB 2004b, *Review of low adhesion research*, Rail Safety and Standards Board, CRF04002, T354.2.

RSSB 2008, *Guidance on wheel/rail low adhesion measurement* GM-GN2642.

RSSB 2009, *Microwave generated steam cleaning of the railhead*, Rail Safety and Standards Board, T539.

RSSB 2012, *Vehicle-track interaction - A guide to RSSB research*, Rail Safety and Standards Board, T930.

Scholdan, D. 2013, "Braking on slippery conditions - Questions for testing and practice", Presentation at Low Adhesion Workshop, DTU.

Spiess, P. 2005, "Schmierfilm auf den Schienen - Systemlösungen für das Herbstproblem", *ZEV rail Glasers Annalen*, vol. 129, pp. 220-225.

Spiess, P. 2013, "Low adhesion - Some aspects and experiences on autumn brake performance", Presentation at Low Adhesion Workshop, DTU. 16/4/13

Spiess, P.2006 Enhancing brake performance under low adhesion conditions. 2006.

Stark, S. 2013, "Prevention adhesion - Story from an operational perspective - Metro Stockholm", Presentation at Low Adhesion Workshop, DTU. 16/4/13

Trafikstyrelsen & Banedanmark 2012, *Glatte skinner*.

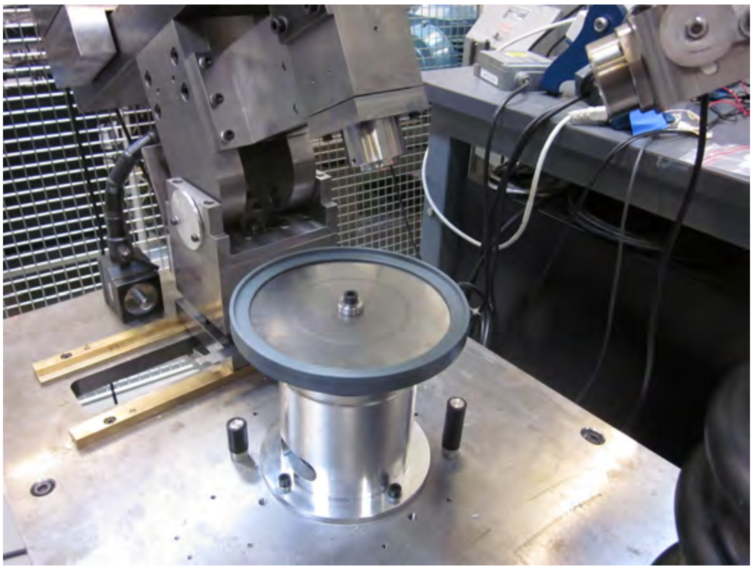
van Steenis, N. H. 2010, *Monitoring train performance in case of low adhesion,* PhD.

Voges, W. & Spiess, P. 2006, "Optimising Services with EMU ET42x in Autumn 2004 and 2005", 7th World Congress on *Railway Research*, Canada.

Study of Friction between Wheel and Track.

Commissioned by DSB.

April 15, 2013



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Contents

1. Preliminary.

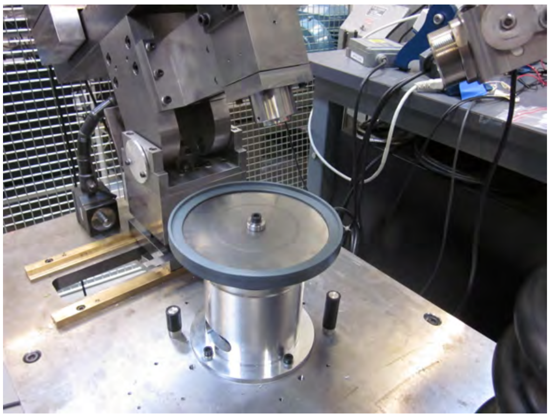
In order to further study the friction between rail material and wheel material, a series of experiments are to be conducted.
These experiments are a continuation of the work, documented in the report "Preliminary Study of Friction between Wheel and Track."
The purpose of these tests is to determine the coefficient of friction under certain test conditions, and to see how the IC3 wheel and IC4 wheel compares in this regard.
As previously, the tests are carried out, using a "Pin On Disc"-testrig.

2. Test rig.

As in earlier experiments, these experiments are performed using a "Pin on Disc" test rig (See figure 1).
The principle of operation involves a rotating disc with a pin pressed down on the surface.
The force, with which the pin is acting, can be adjusted by sliding a weight along the arm (Please see figure 1 (b)). In addition to the force, it is also possible to adjust the rotational speed of the disc.
The test rig is fitted with a force transducer that enables a calculation of the shaft torque, which in turn is used to determine the coefficient of friction.
Collection of data is carried out using Labview.

Test rig specifications:

Minimum contact pressure using a pin with a diameter of 5mm.:	3.97 $[MPa]$
Maximum contact pressure using a pin with a diameter of 5mm.:	84 $[MPa]$
Max. speed:	0.64 $[m/s]$

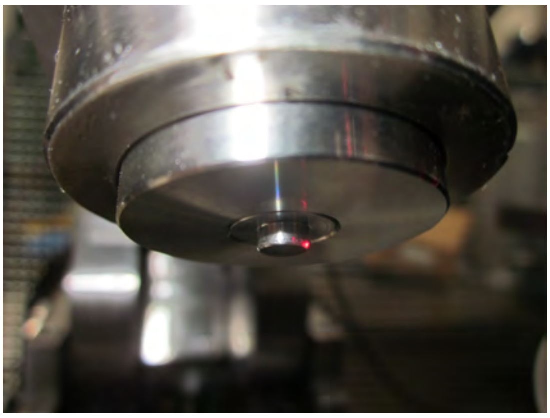


(a) Photo of test rig with the arm in elevated position.

(b) The steel block can be displaced along the arm, in order to change load.

(c) Photo of test disc

(d) Photo of test pin



(e) Photo of test pin mounted in adapter.

Figure 1: Photos showing "'Pin on Disc"'test rig.

3. Manufacturing of disc and pins.

3.1 Disc.

The disc used in these experiments is made from a piece of UIC 60 type rail. Please see figure 37 and 35 in appendix).

3.2 Pins

The pins are made from an IC3 wheel and an IC4 wheel.
On figure 2, we see how cylinders have been cut out from the wheel by means of a waterjet cutter.
These cylinders are subsequently manufatured into test pins (See drawing of pin on figure 36 in appendix).

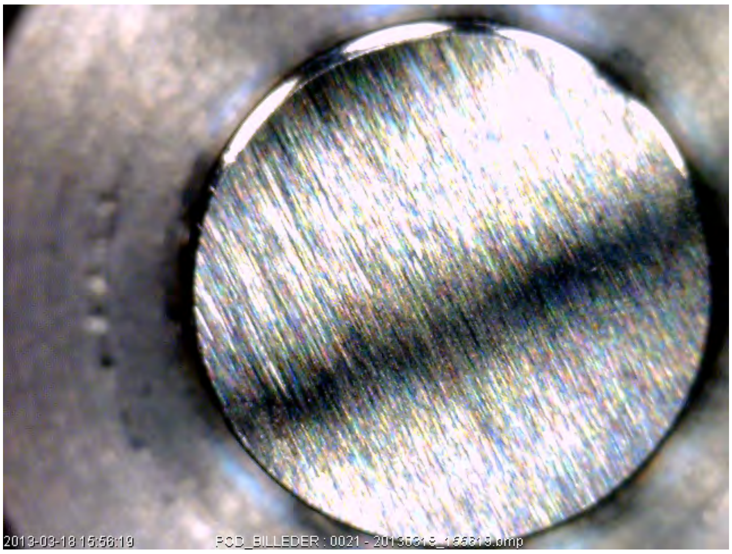
The IC3 wheel is made from R8T steel, while the IC4 wheel is made from R7T steel (Pleace see table on figure 34 in appendix.).

(a) (b)

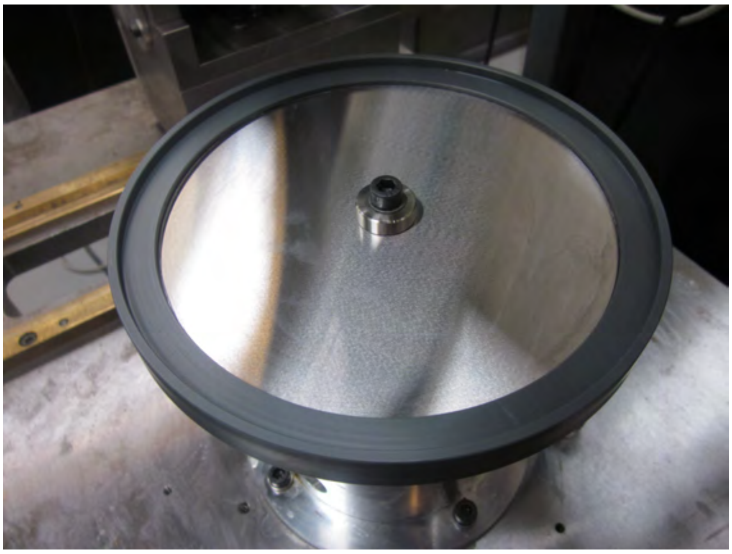
Figure 2: Piece of train wheel.

3.3 Surface finish of disc and pin.

In order to prevent tearing of the disc and pin, as described earlier in the report "Preliminary Study of Friction Between Wheel and Rail", both disc and pins have been ground to reduce the surface roughness (Please see figure 3).



(a) Close up of pin with ground surface.



(b) Disc with ground surface.

Figure 3: Disc and pin with ground surfaces.

4. Lubricants.

Two kinds of lubricants have been used in the experiments:

1. A soap with the tradename ”Plejevask m. voks”, normally used to clean floors.
   This soap is made by the company ”Knud E. Dan A/S”. (Please see figure 4(a) and datasheet in the appendix.)

2. A Rape seed oil, normally used as cooking oil. (Please see figure 4(b).)

These two types of lubricants have previously been used in full scale tests.

(a) Soap used in the experiments.

(b) Rape seed oil used in the experiments.

Figure 4: Lubricants used in the experiments.

5. Test results.

In this section, the data collected in the experiments will be presented in the form of both xy-plots and polar-plots.
The xy-plots show how the coefficient of friction develops with respect to distance, where as the polar plots show how the coefficient of friction changes with respect to the angular position of the disc.
The coefficient of friction fluctuates significantly in some of the experiments, and here the corresponding polar plots reveal that these fluctuations are cyclic.

Please note that, in the first series of experiments, the disc was not repositioned to the same angular starting point before each experiment. This means that the angular position of zero degrees on the polar plots will not correspond to the same angular position of the disc from plot to plot.

The experiments were carried out by first applying lubricant to the disc and then start the experiment. If, by the end of a run, the coefficient of friction had not yet stabilized, the experiment was repeated.
The plots show the last run for each experiment.

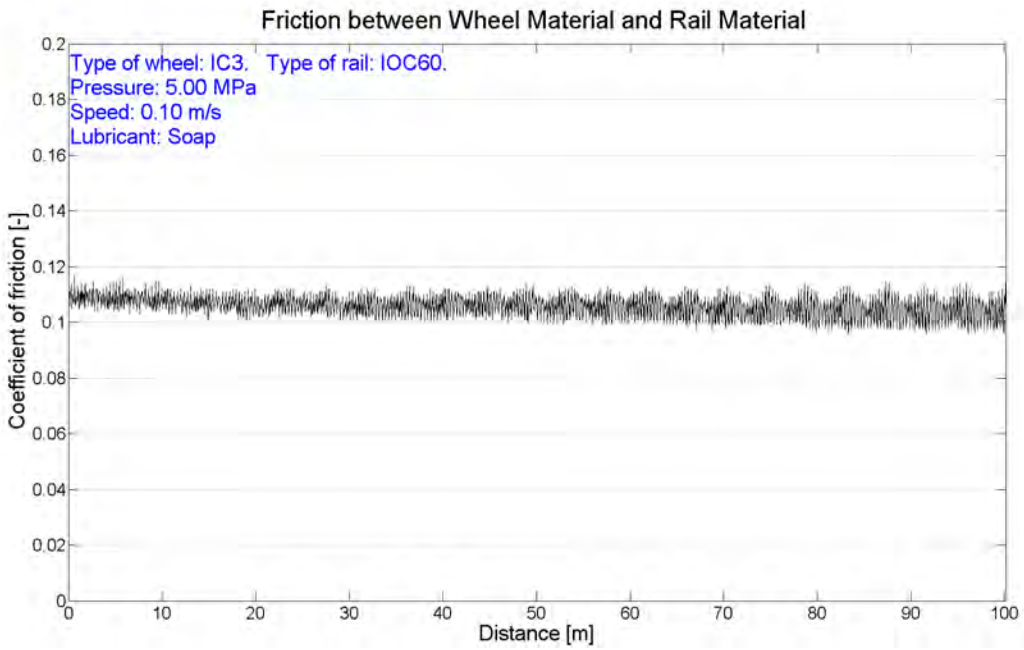
5.1 First series of experiments.

The first series of experiments were carried out in accordance with experimental plan-1 (Please see experimental plans in appendix).
These experiments were performed in a randomized sequence.

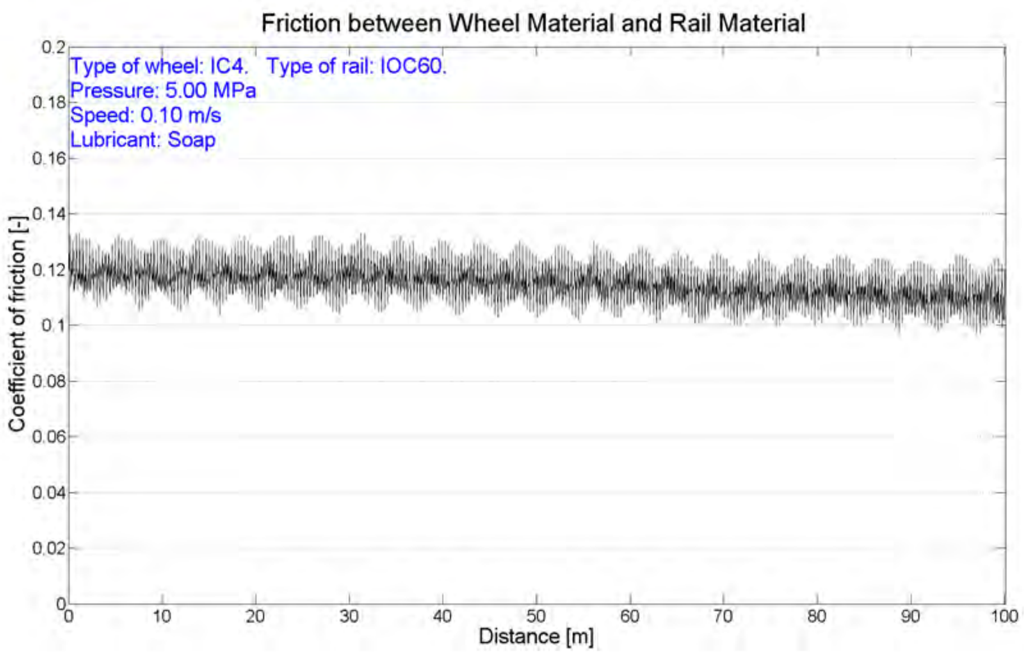
The same track on the disc was used in all 12 experiments.

5.1.1 Experiments with soap.

On figure 5, 7 and 9 we see the xy-plots for an IC3-pin and IC4-pin, at a contact pressure of 5MPa, 15MPa and 25MPa respectively.
The graphs does not show a significant difference between the IC3 and IC4 material.
The corresponding polar plots on figure 6, 8 and 10 show that the friction does not vary significantly with the angular position of the disc.

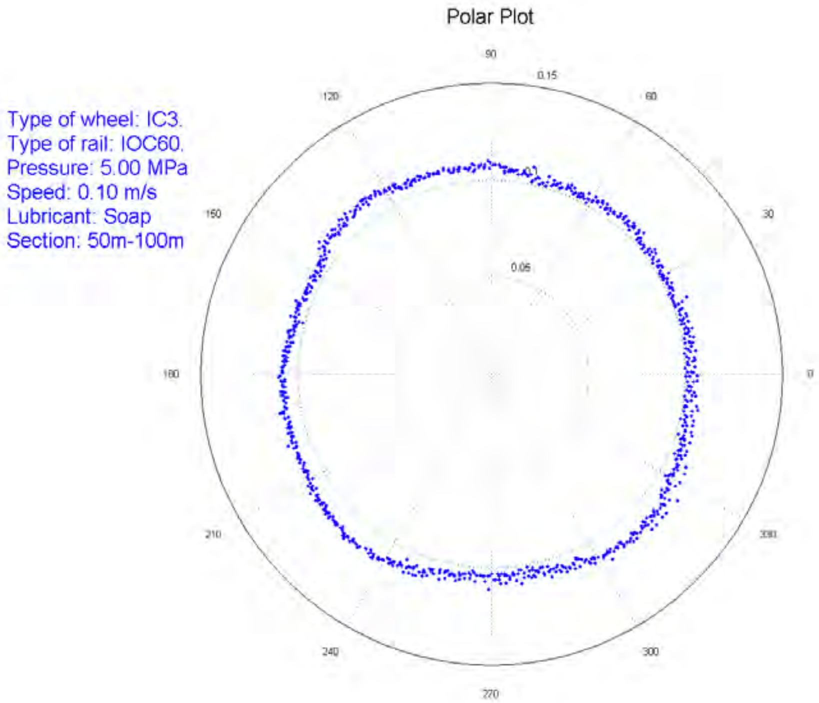


(a) Experiment with soap and IC3-pin at 5MPa

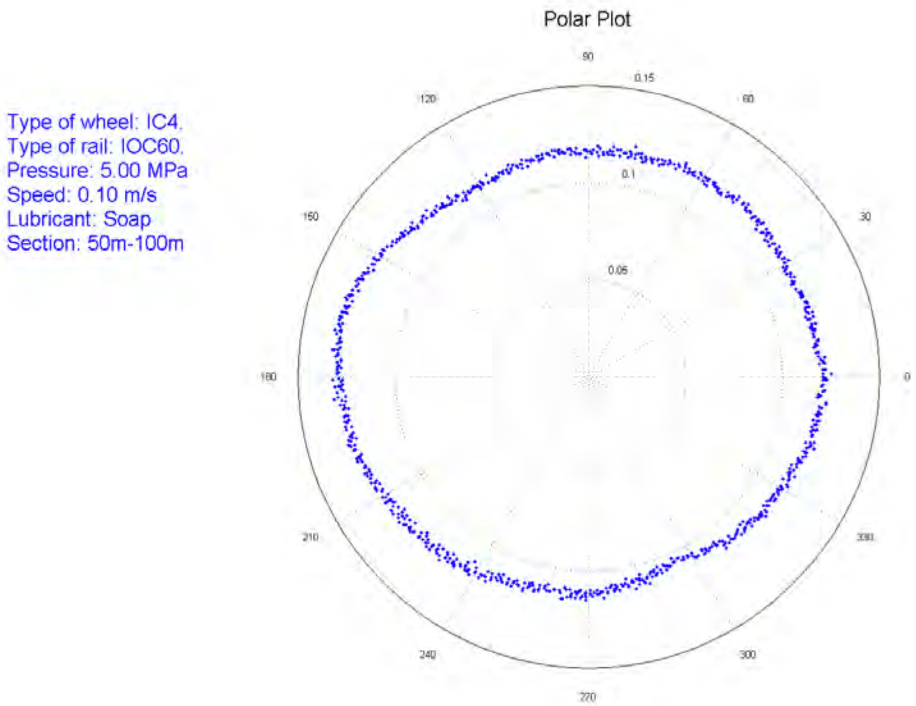


(b) Experiment with soap and IC4-pin at 5MPa

Figure 5: Experiments with soap at 5MPa

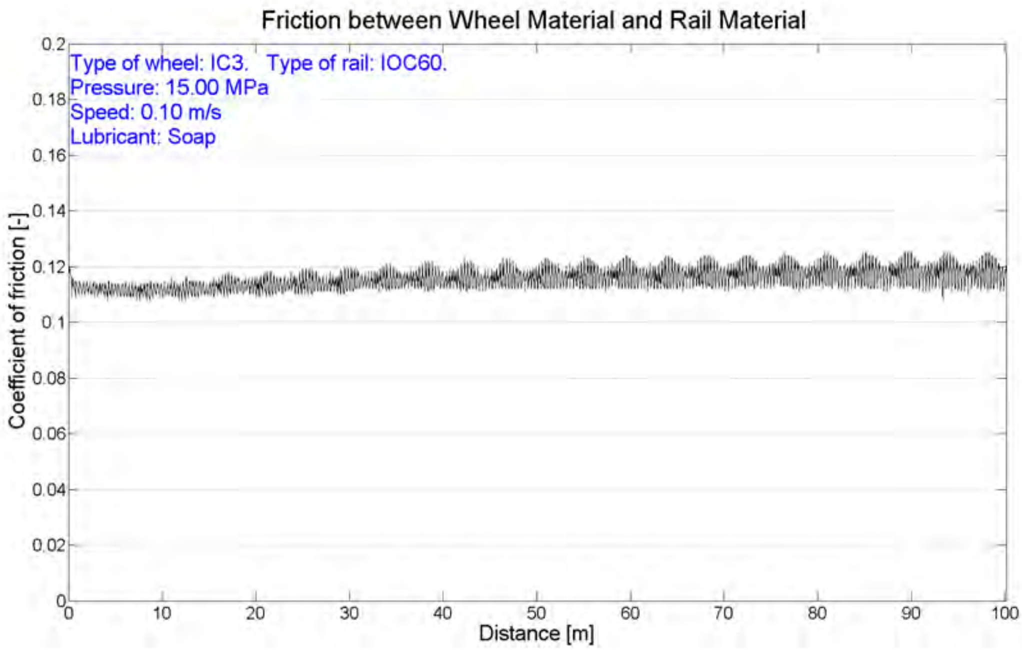


(a) Experiment with soap and IC3-pin at 5MPa

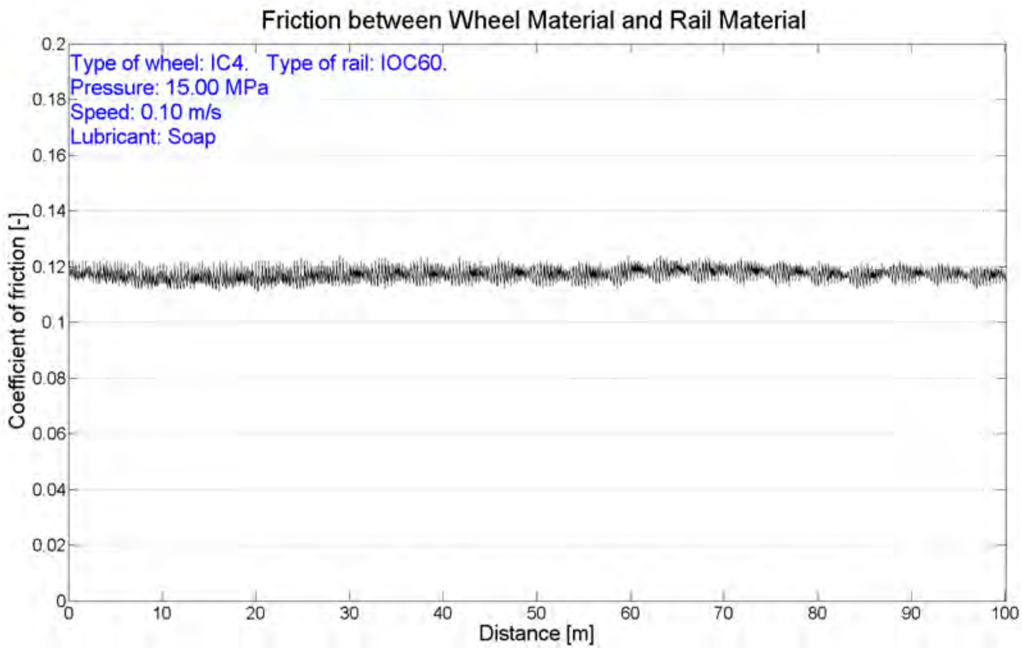


(b) Experiment with soap and IC4-pin at 5MPa

Figure 6: Experiments with soap at 5MPa

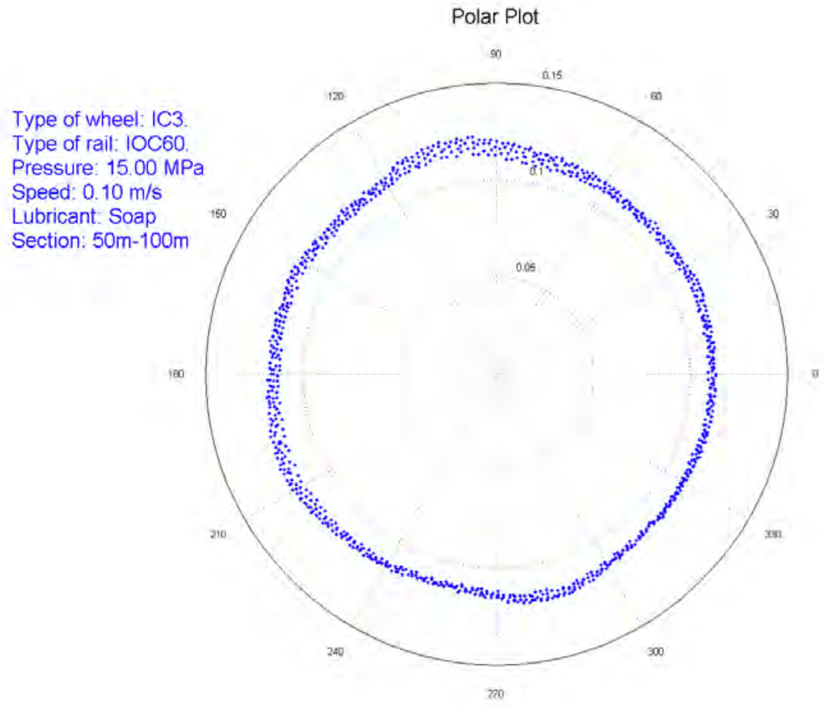


(a) Experiment with soap and IC3-pin at 15MPa

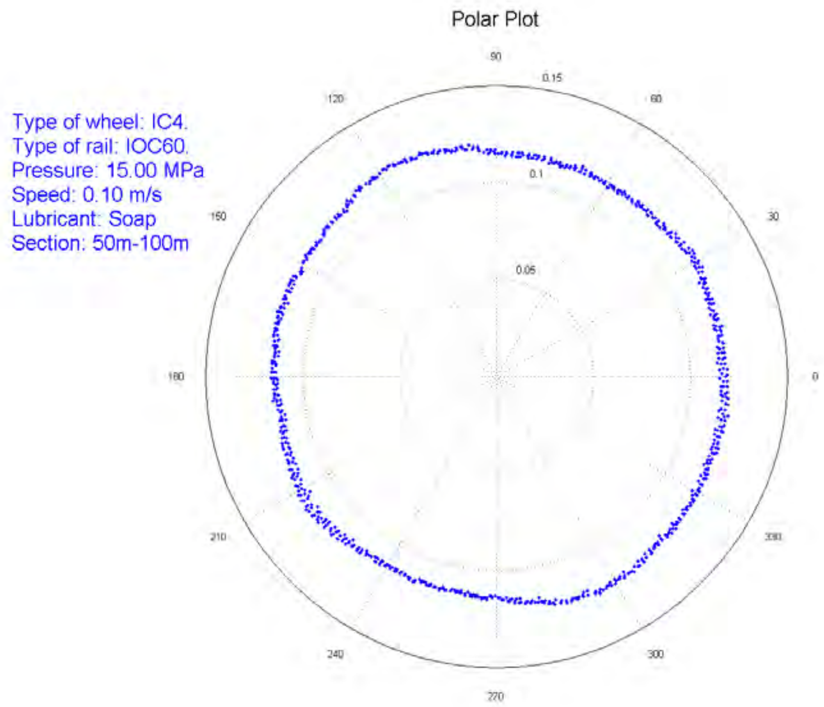


(b) Experiment with soap and IC4-pin at 15MPa

Figure 7: Experiments with soap at 15MPa

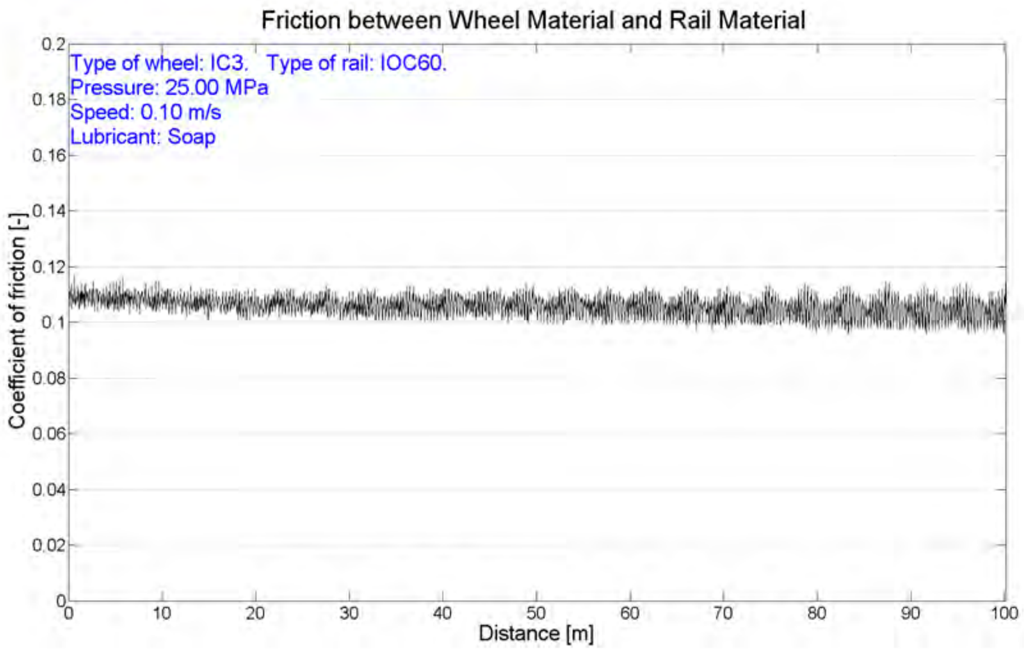


(a) Experiment with soap and IC3-pin at 15MPa

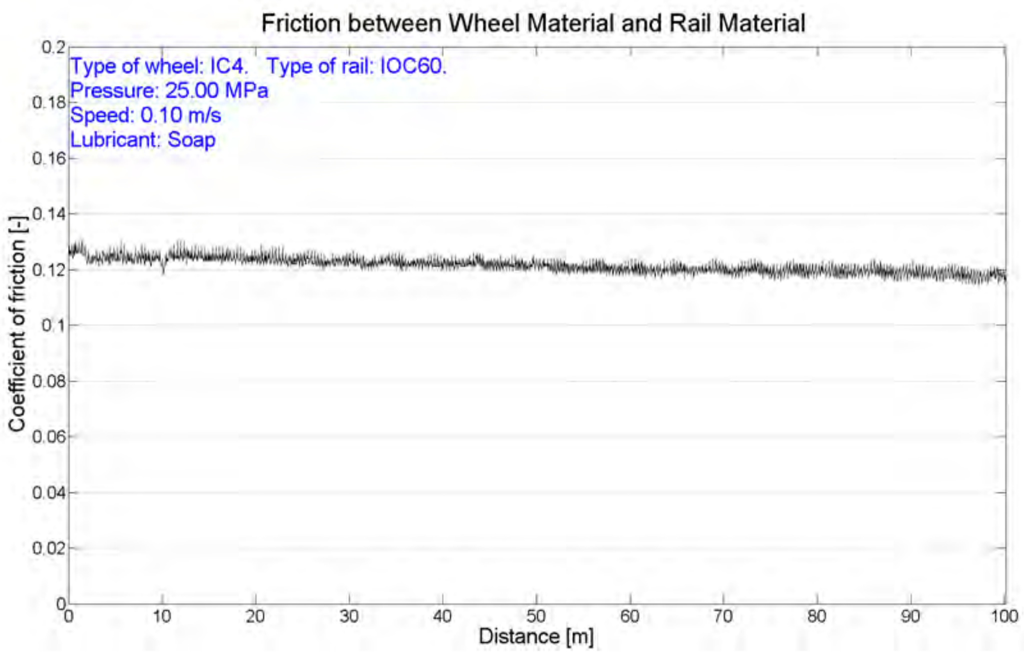


(b) Experiment with soap and IC4-pin at 15MPa

Figure 8: Experiments with soap at 15MPa

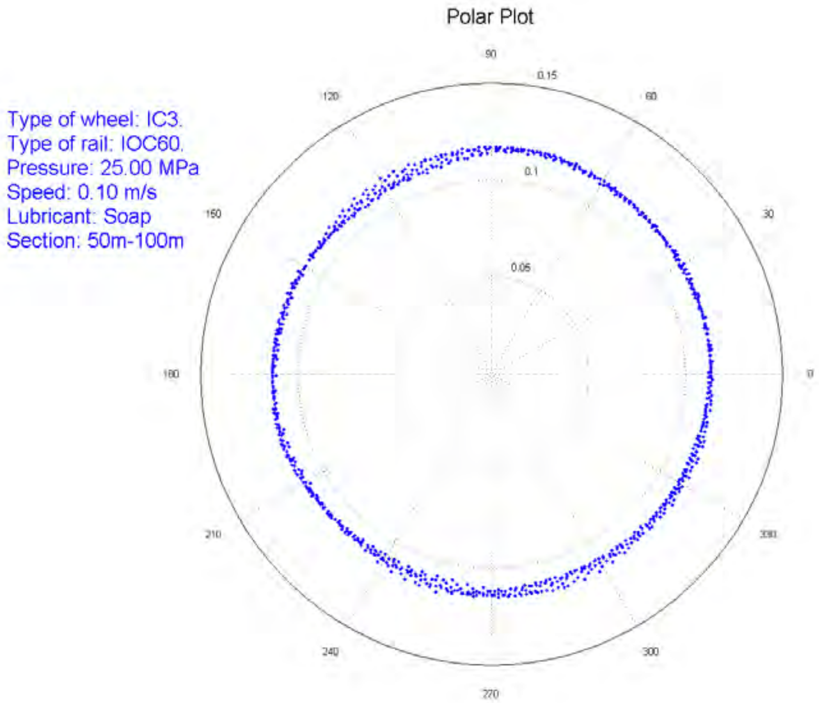


(a) Experiment with soap and IC3-pin at 25MPa

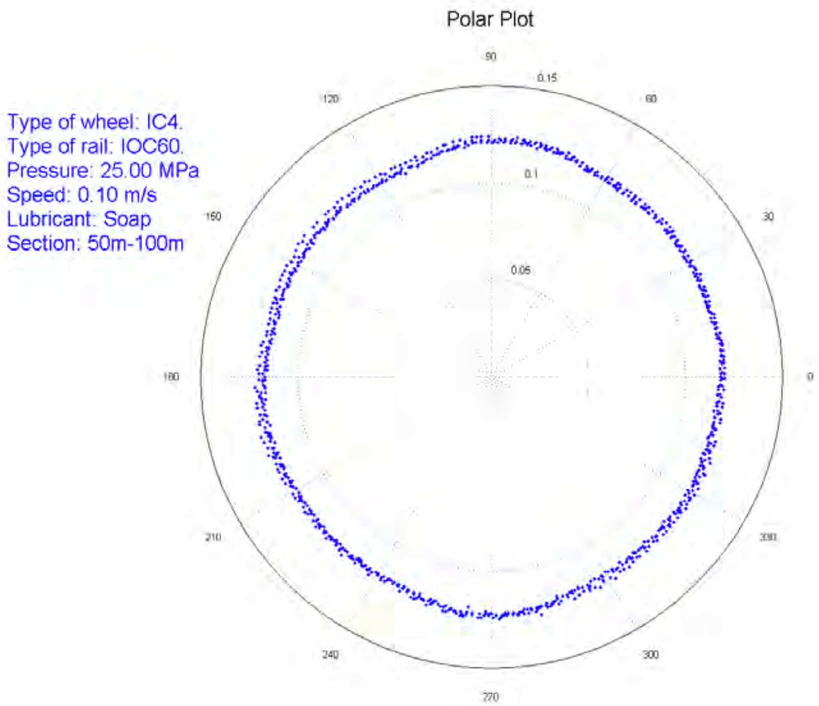


(b) Experiment with soap and IC4-pin at 25MPa

Figure 9: Experiments with soap at 25MPa



(a) Experiment with soap and IC3-pin at 25MPa

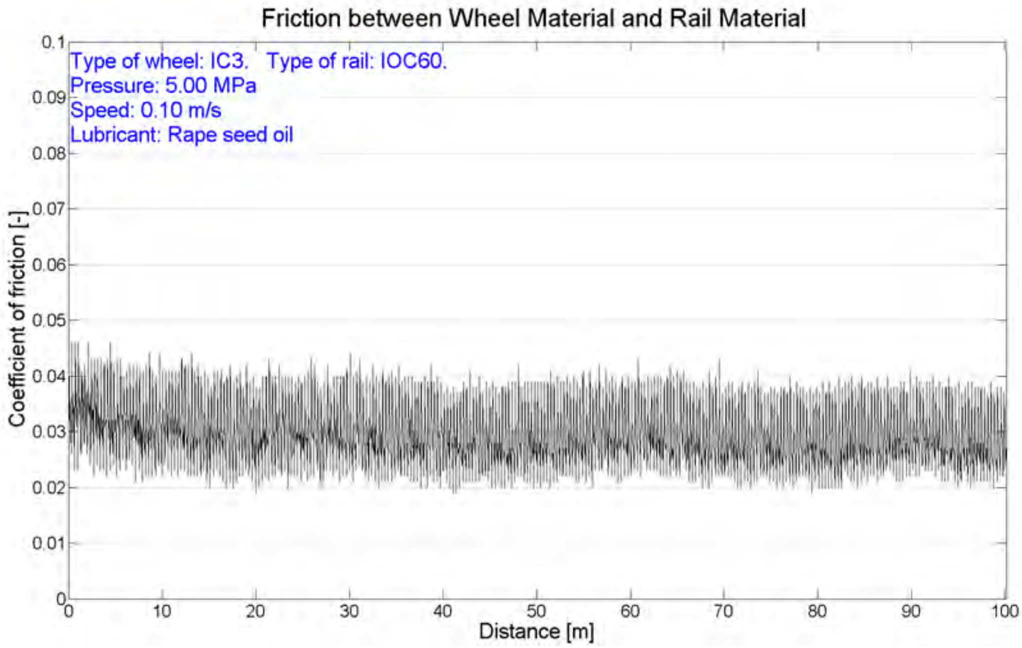


(b) Experiment with soap and IC4-pin at 25MPa

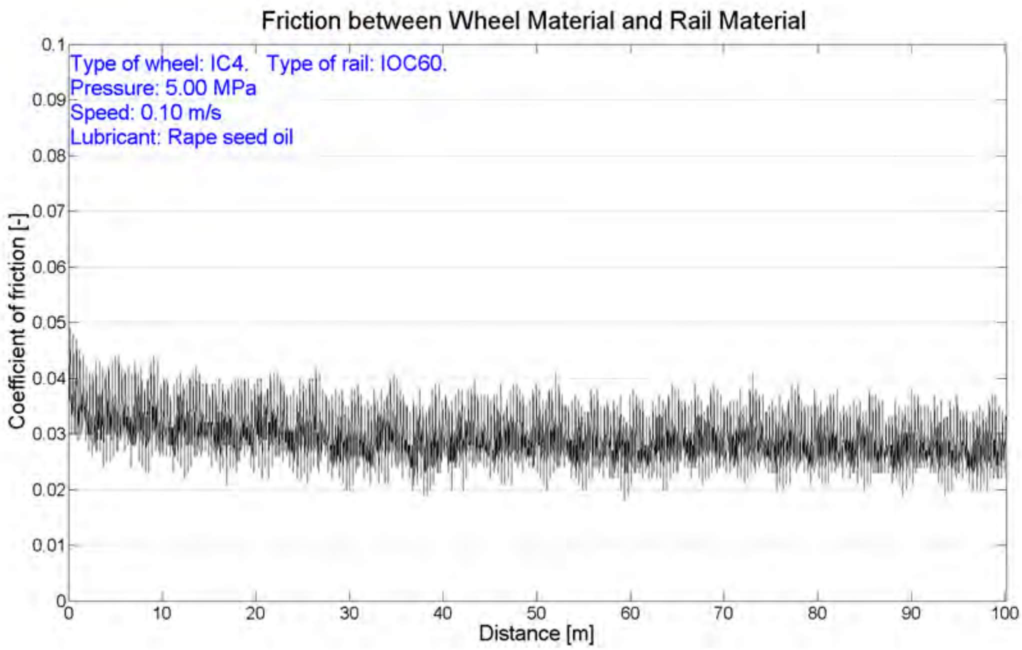
Figure 10: Experiments with soap at 25MPa

5.1.2 Experiments with rape seed oil.

On figure 11, 13 and 15 we see that the friction is generally lower than in the experiments with soap. We also see that the coefficient of friction fluctuates much more than in the experiments with soap. On figure 12, 14 and 16 we can see that these fluctuations are cyclic.

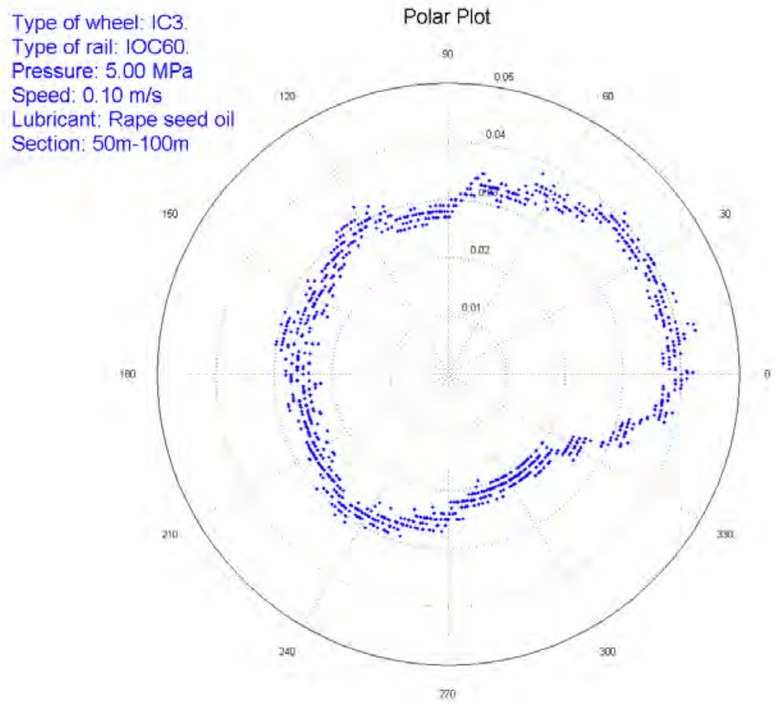


(a) Experiment with rape seed oil and IC3-pin at 5MPa

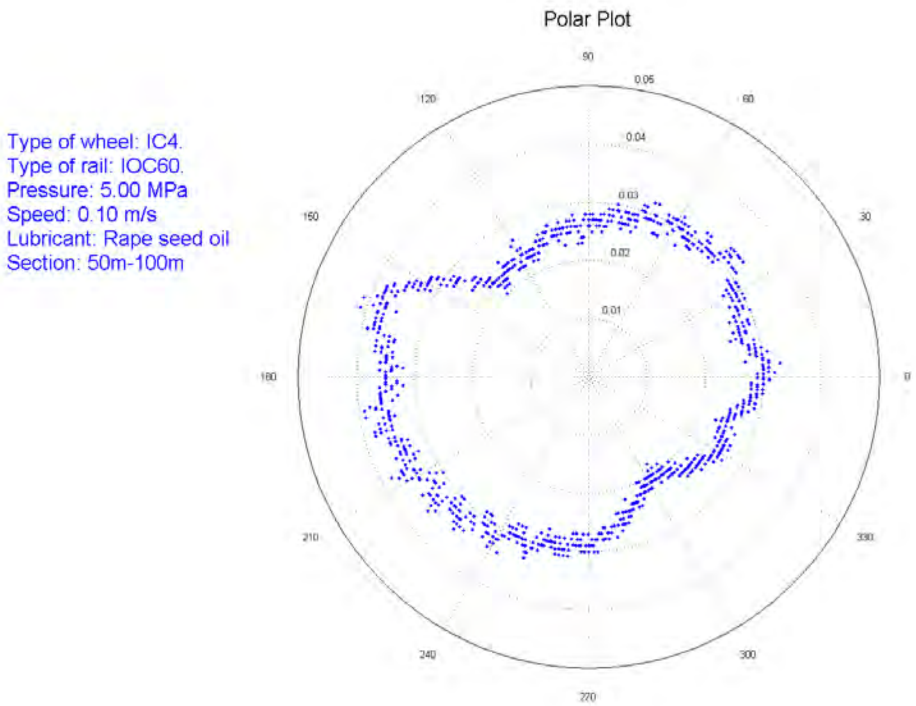


(b) Experiment with rape seed oil and IC4-pin at 5MPa

Figure 11: Experiments with rape seed oil at 5MPa

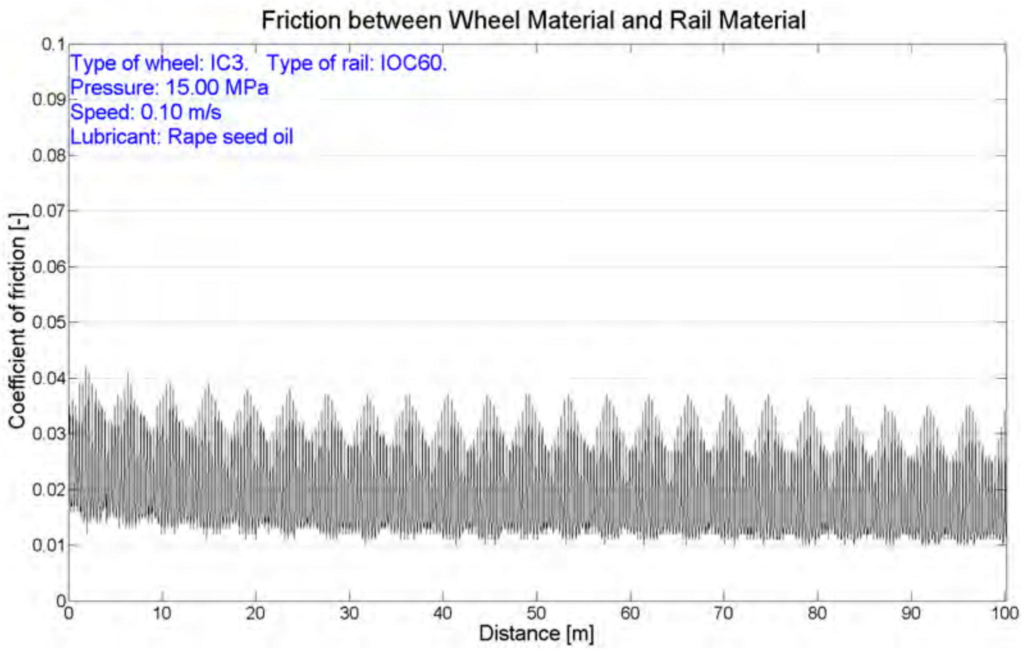


(a) Experiment with rape seed oil and IC3-pin at 5MPa

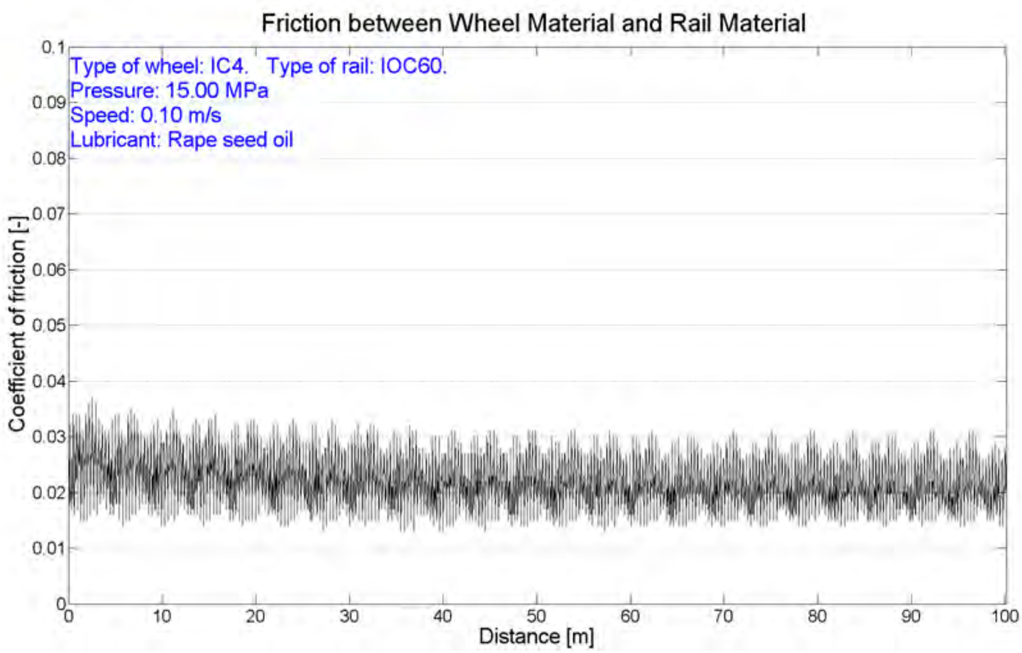


(b) Experiment with rape seed oil and IC4-pin at 5MPa

Figure 12: Experiments with rape seed oil at 5MPa

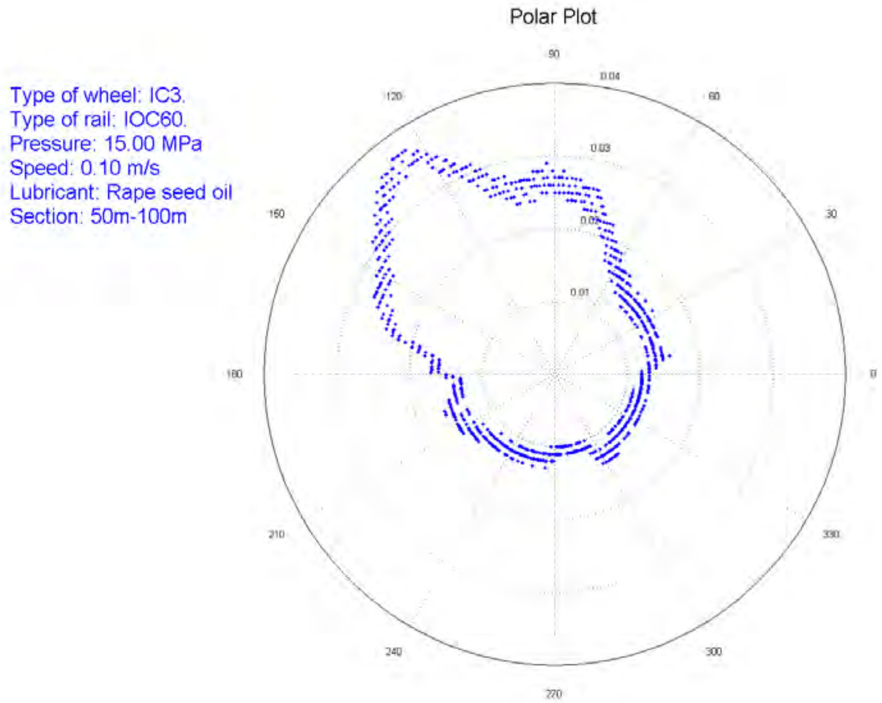


(a) Experiment with rape seed oil and IC3-pin at 15MPa

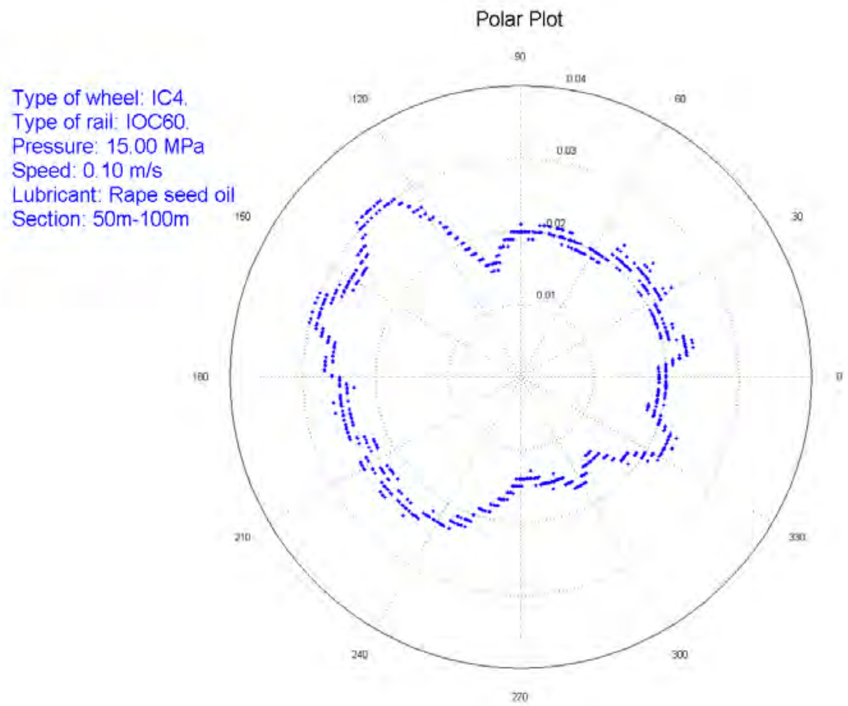


(b) Experiment with rape seed oil and IC4-pin at 15MPa

Figure 13: Experiments with rape seed oil at 15MPa

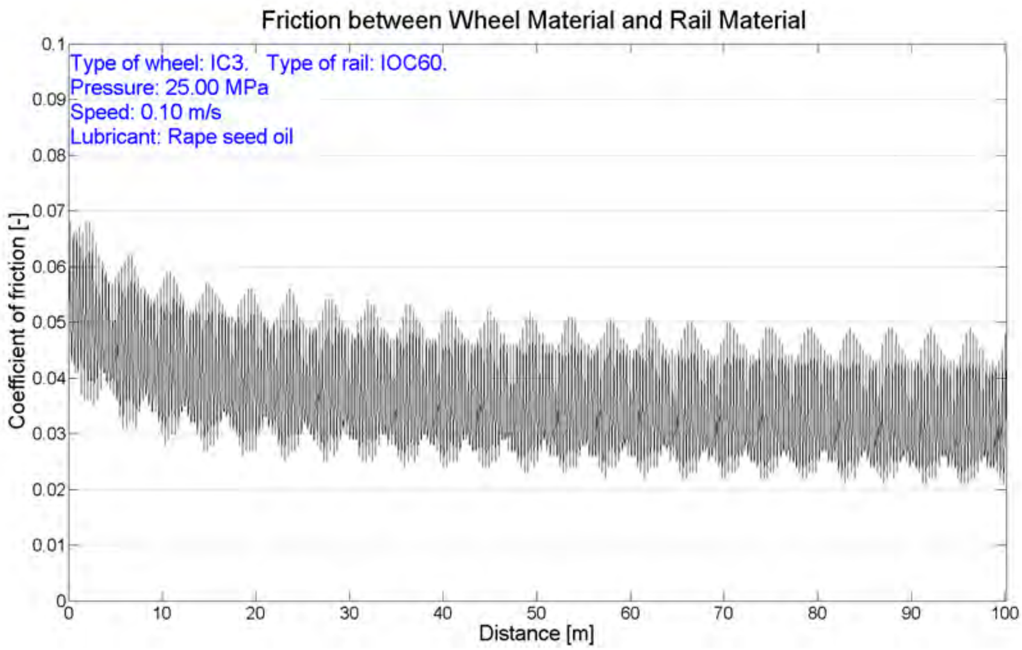


(a) Experiment with rape seed oil and IC3-pin at 15MPa

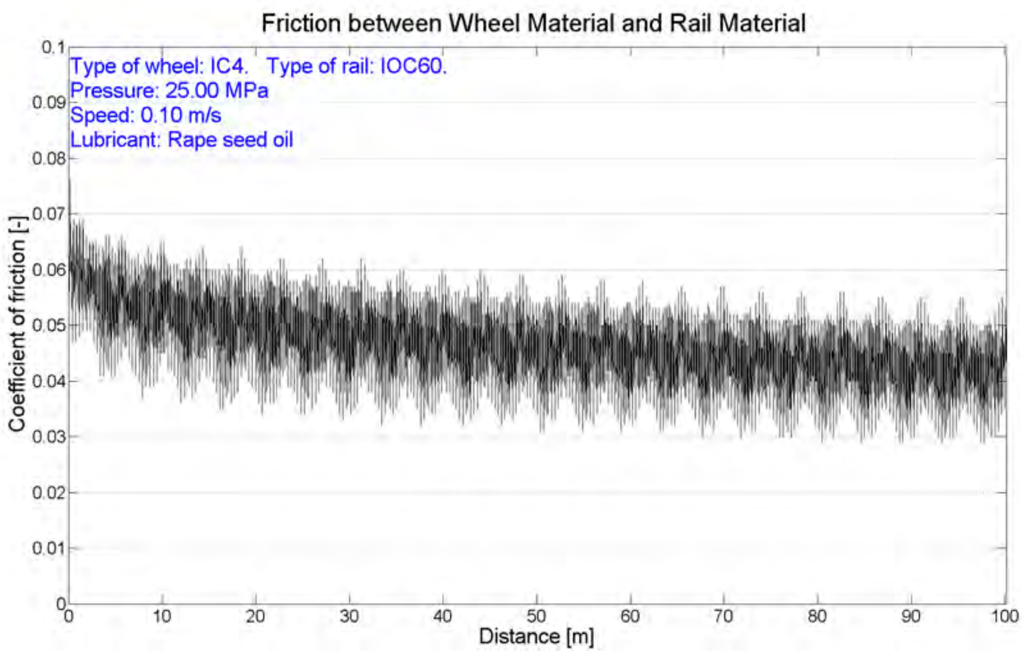


(b) Experiment with rape seed oil and IC4-pin at 15MPa

Figure 14: Experiments with rape seed oil at 15MPa

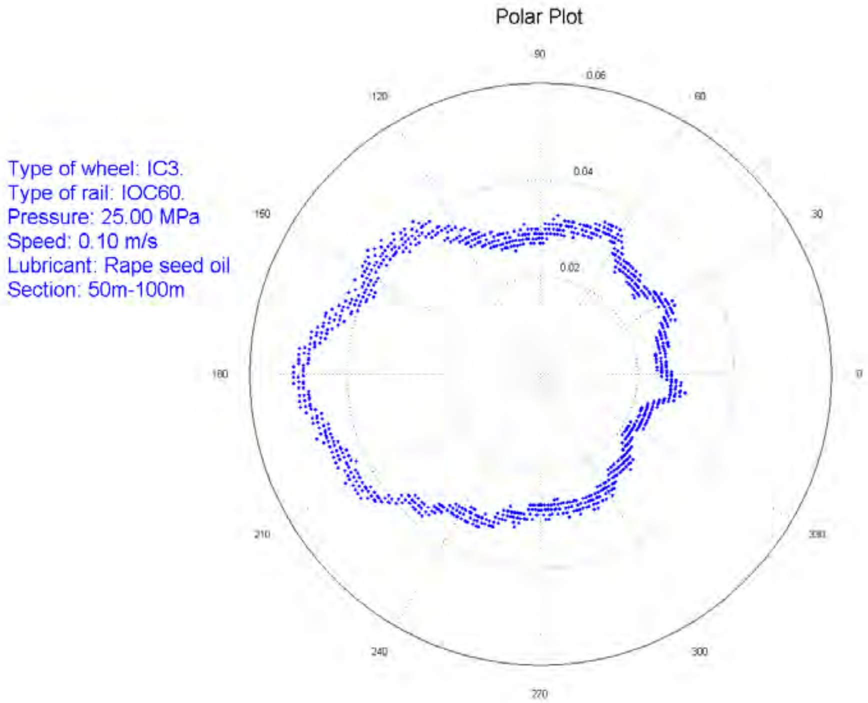


(a) Experiment with rape seed oil and IC3-pin at 25MPa

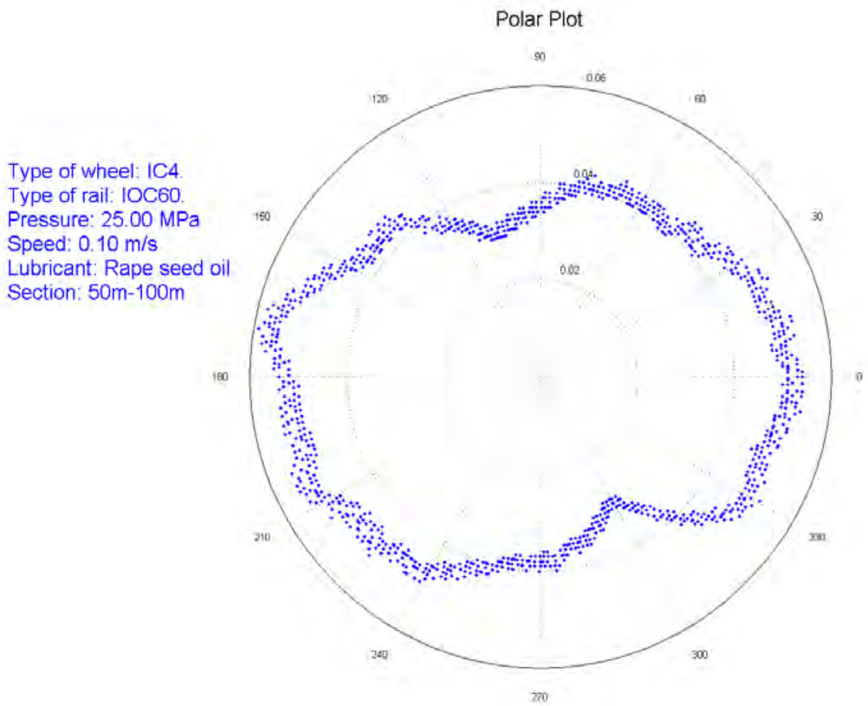


(b) Experiment with rape seed oil and IC4-pin at 25MPa

Figure 15: Experiments with rape seed oil at 25MPa



(a) Experiment with rape seed oil and IC3-pin at 25MPa



(b) Experiment with rape seed oil and IC4-pin at 25MPa

Figure 16: Experiments with rape seed oil at 25MPa

5.2 Second series of experiments.

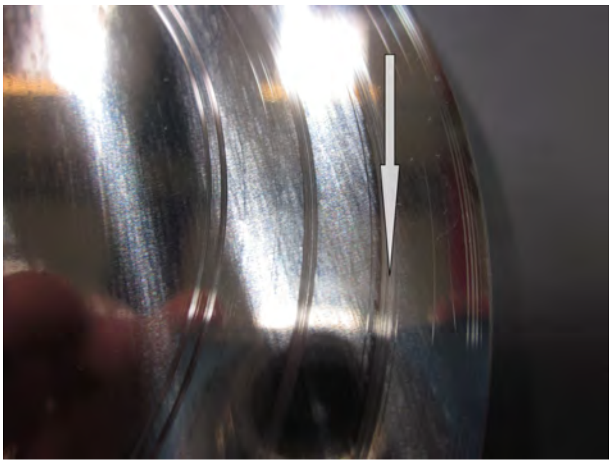
In order to try to reproduce the results from the first series of experiments, it was decided to perform a second series of experiments. The second series of experiments were originally intended to be carried out in accordance with experimental plan-2. (Please see experimental plans in appendix.).

As in the case with experimental plan-1, the tests in experimental plan-2 were also randomized.
Experiment number 1 in experimental plan 2 required a pressure of 25MPa, and soap to be used as lubricant. This first experiment led to tearing of the pin, the result of which can be seen on figure 17

Because of a limited number of pins, it was decided to do the second series of experiments according to experimental plan-3. Here the experiments with soap and the experiments with oil are split up into two parts, and the pressure is gradually increased.

Two different tracks were used in the experiments with soap. One track for the IC3 pin and another track for the IC4 pin.
After the experiments with soap, the disc was ground and the the experiments with oil was started.
As in the case with the soap experiments, the oil experiments were carried out using separate tracks for the IC3 pin and the IC4 pin.

(a) Pin after tearing.

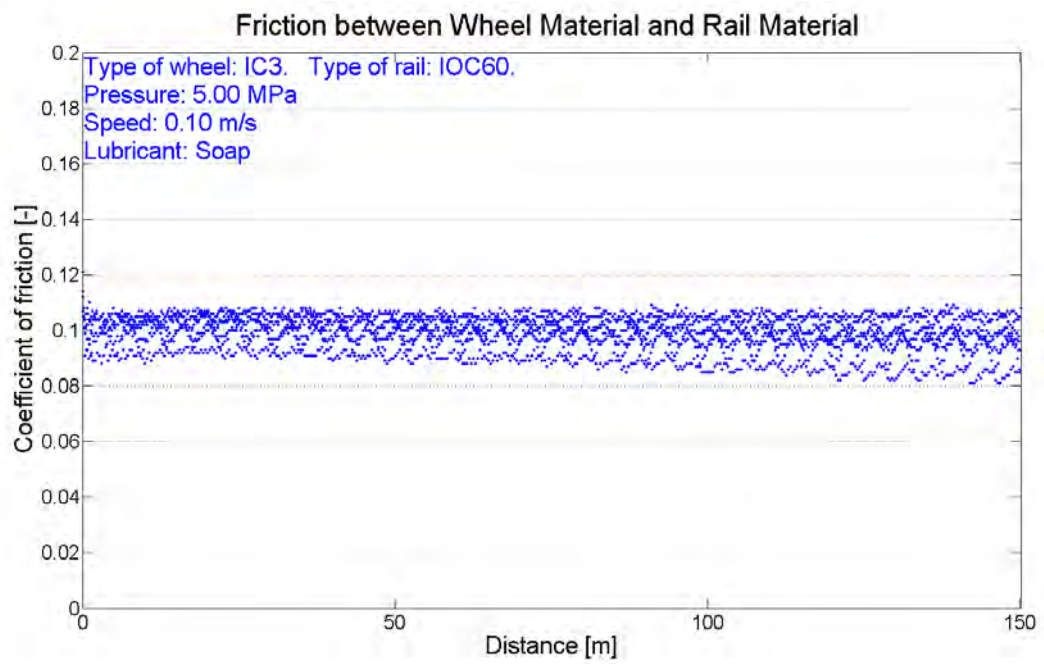


(b) Disc after tearing.

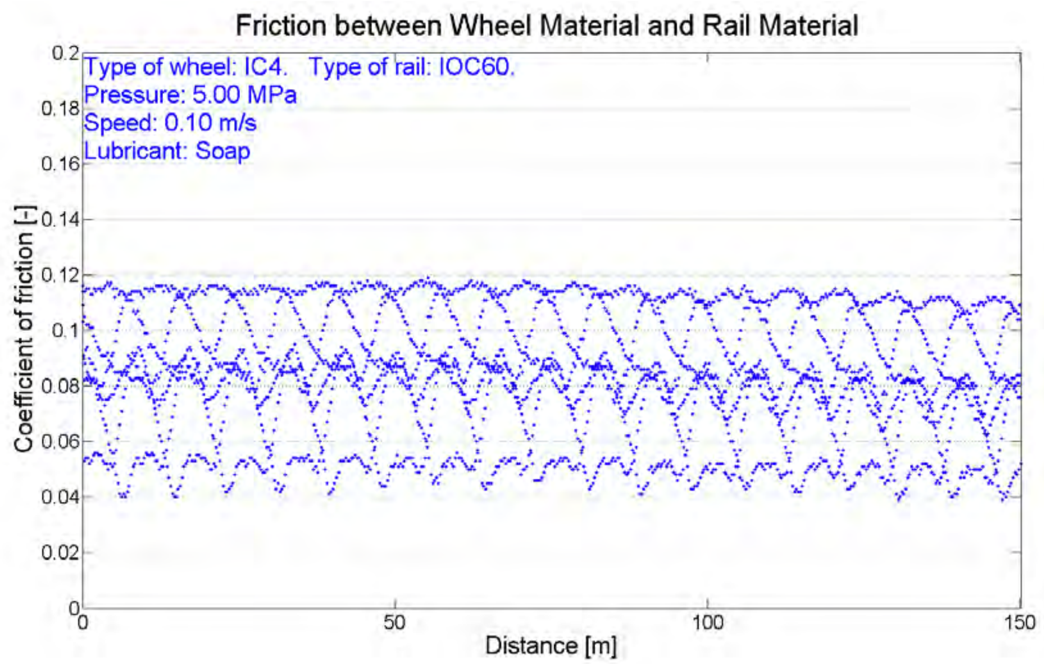
Figure 17: Disc and pin after tearing.

5.2.1 Experiments with soap.

On figure 22 (a) we see a significant increase in friction after about 62 meters. This is the result of the pin being teared. The coefficient of friction stabilizes again, and then increases again at about 80 meters. After this the experiment was stopped in order to avoíd further damage to the disc.

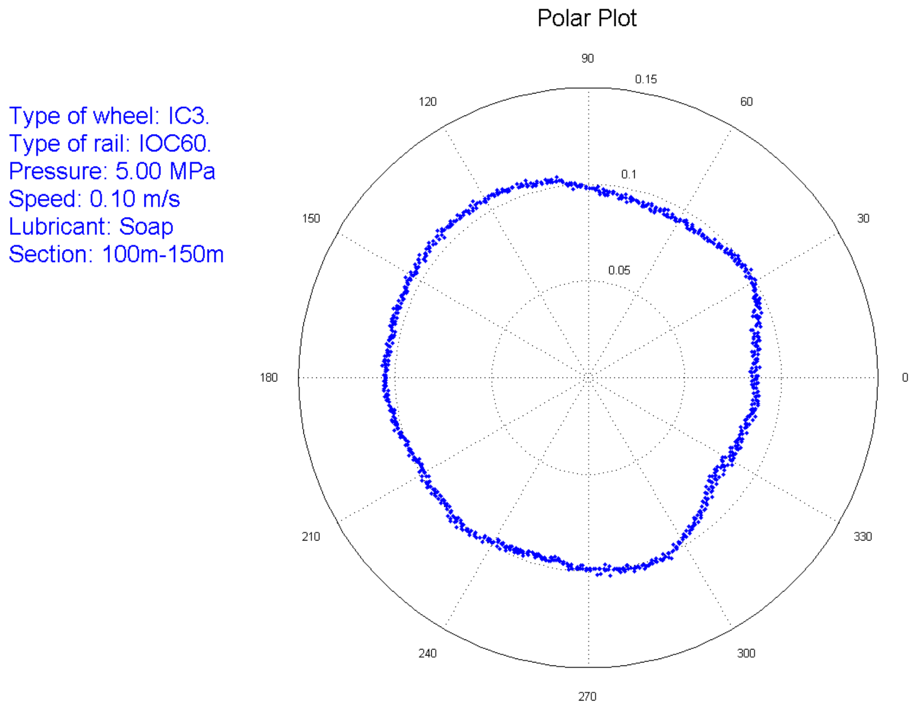


(a) Experiment with soap and IC3-pin at 5MPa

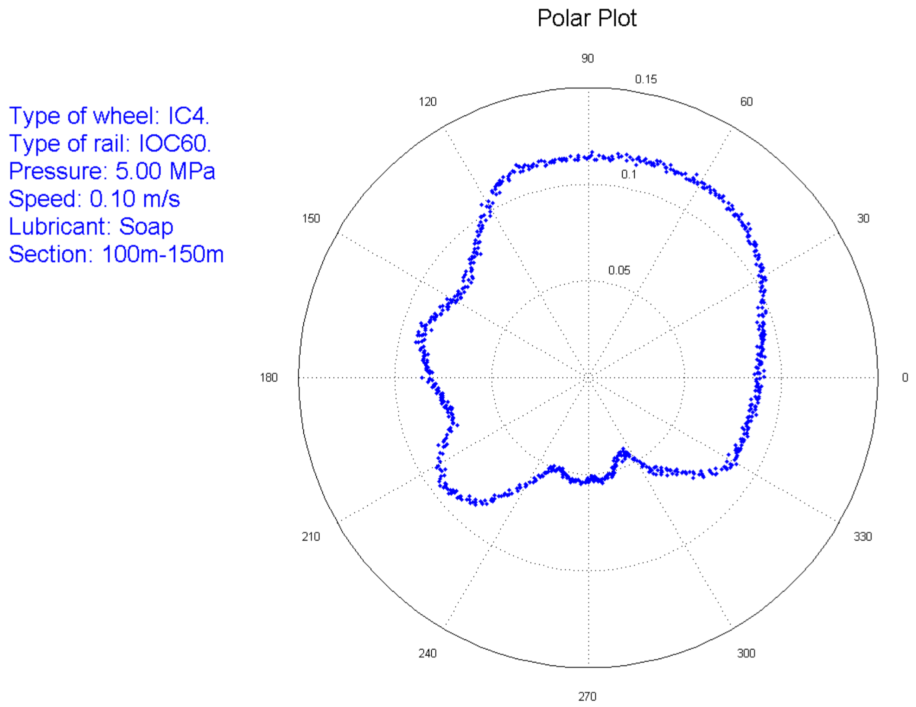


(b) Experiment with soap and IC4-pin at 5MPa

Figure 18: Experiments with soap at 5MPa

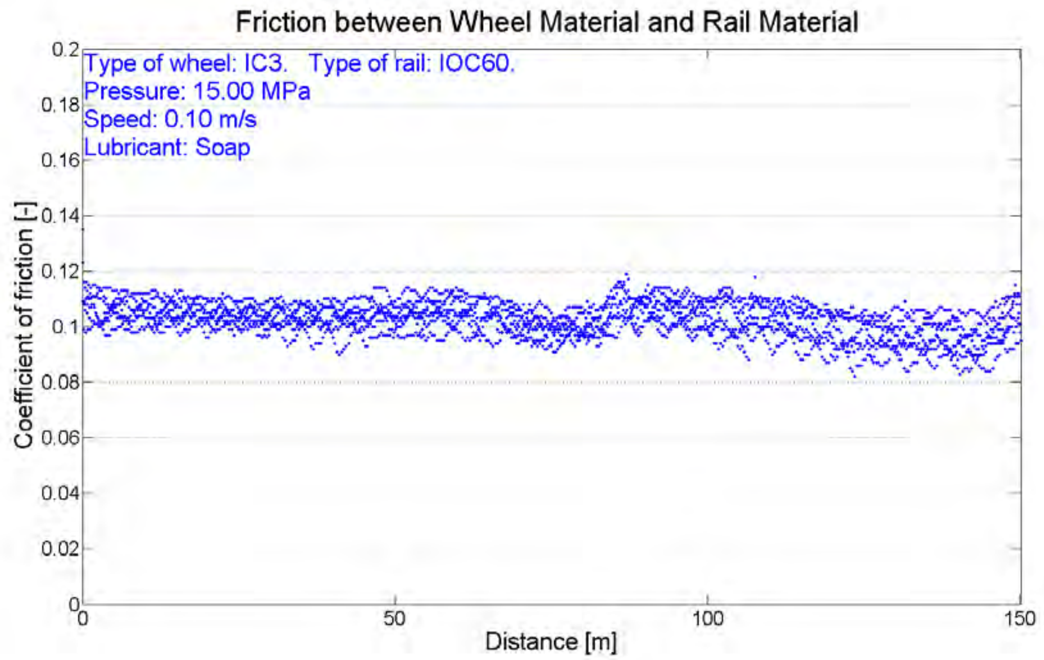


(a) Experiment with soap and IC3-pin at 5MPa

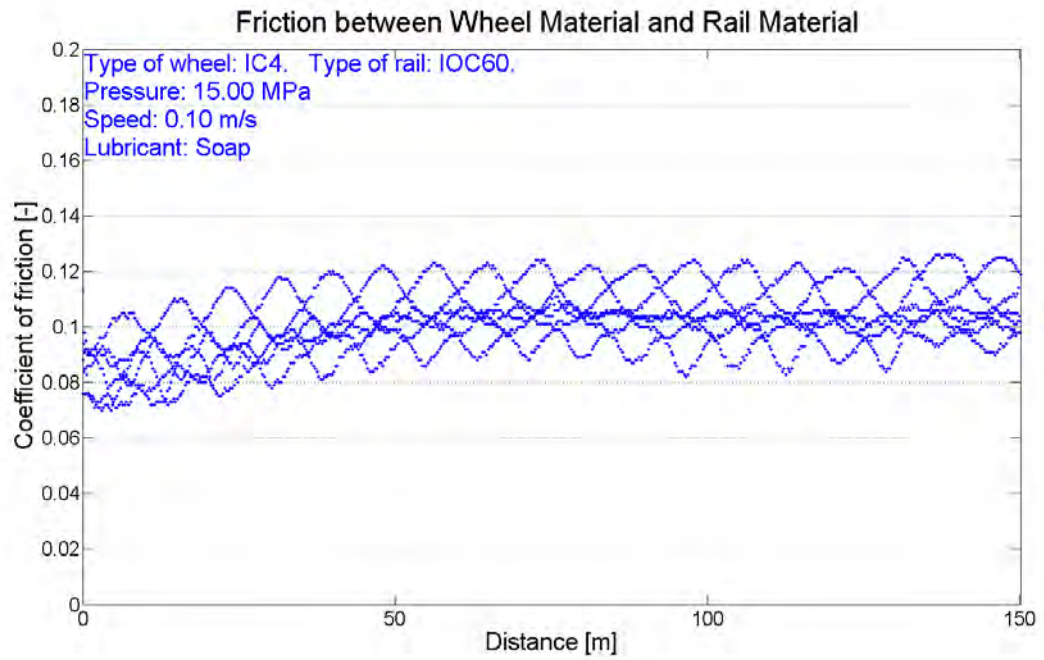


(b) Experiment with soap and IC4-pin at 5MPa

Figure 19: Experiments with soap at 5MPa

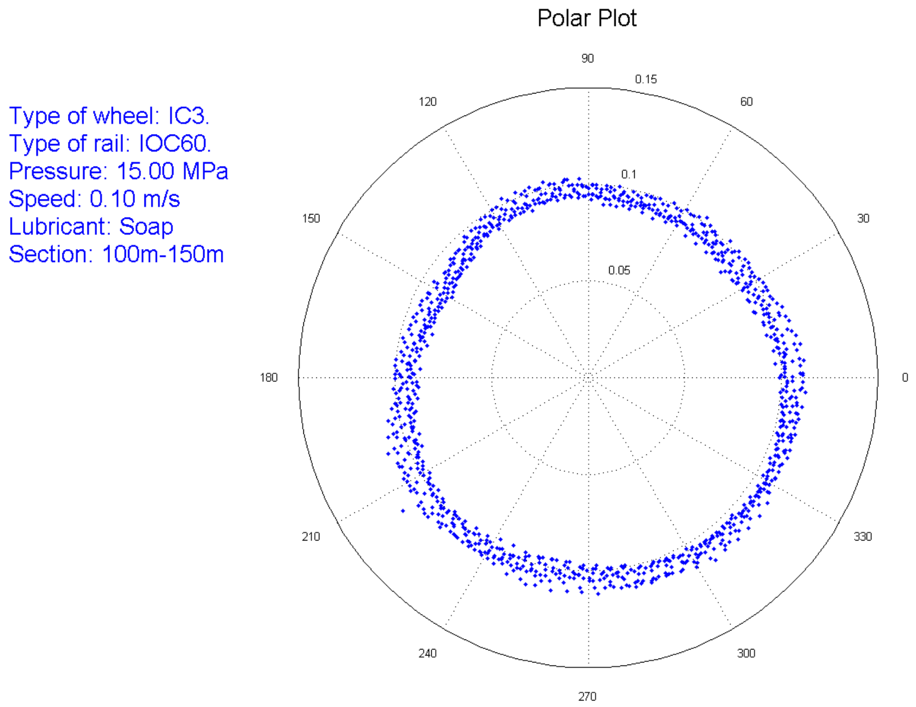


(a) Experiment with soap and IC3-pin at 15MPa

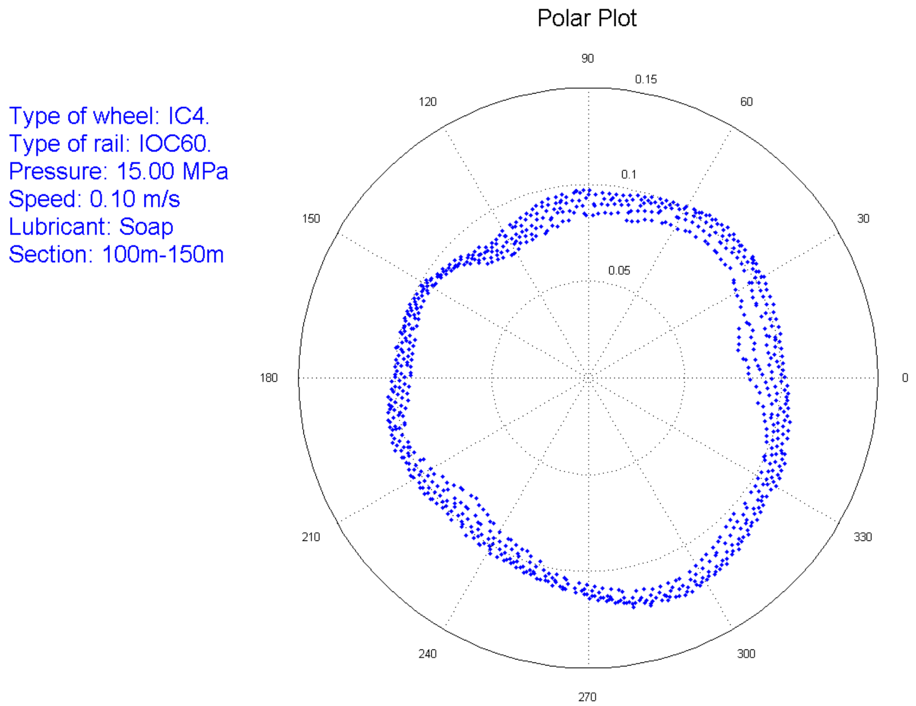


(b) Experiment with soap and IC4-pin at 15MPa

Figure 20: Experiments with soap at 15MPa

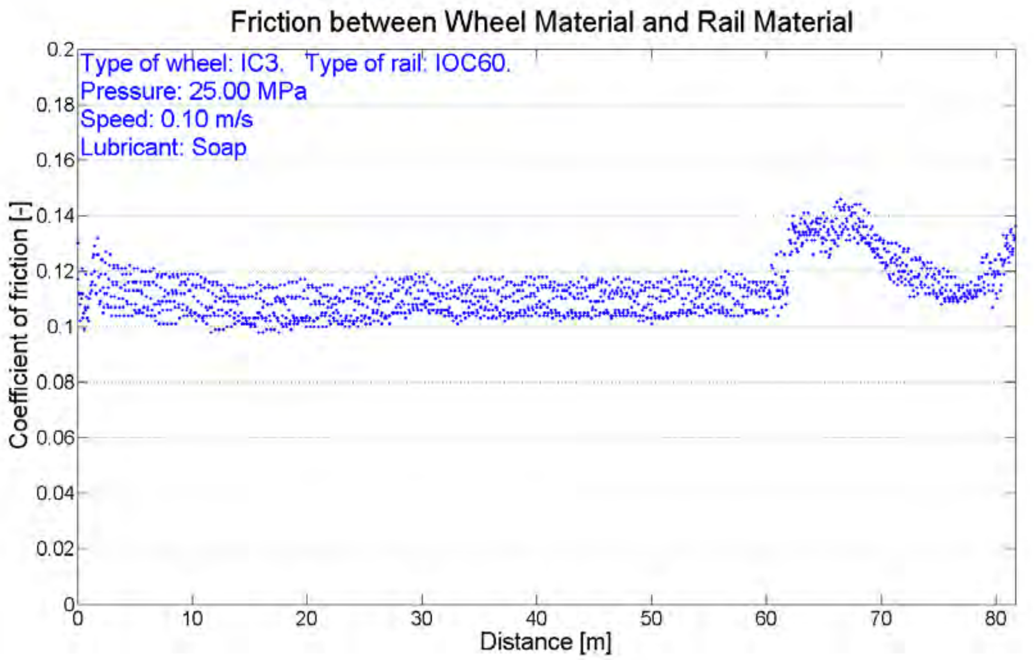


(a) Experiment with soap and IC3-pin at 15MPa

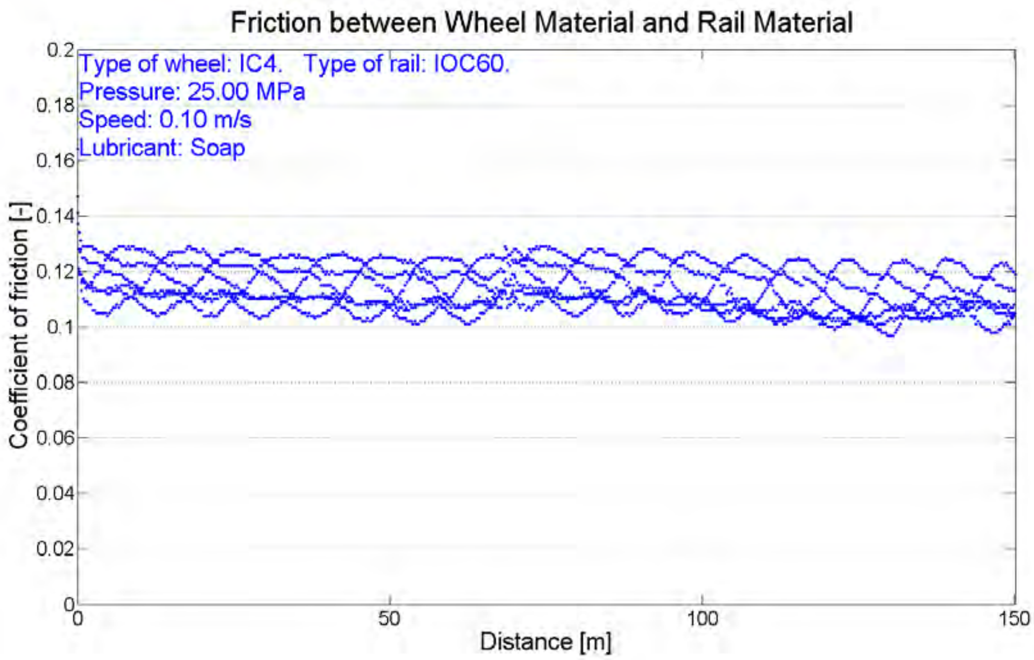


(b) Experiment with soap and IC4-pin at 15MPa

Figure 21: Experiments with soap at 15MPa

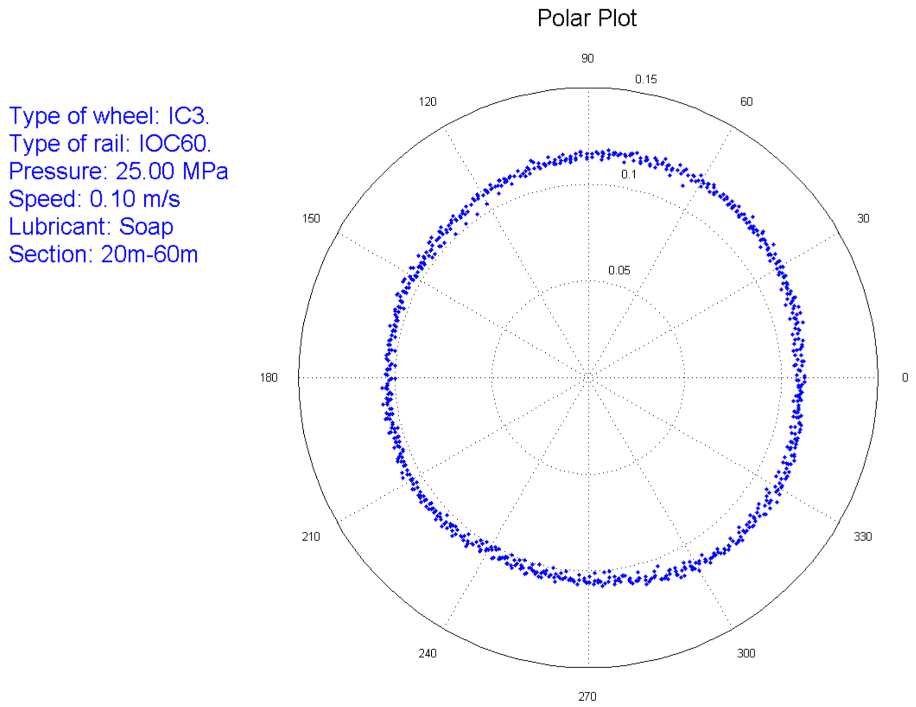


(a) Experiment with soap and IC3-pin at 25MPa

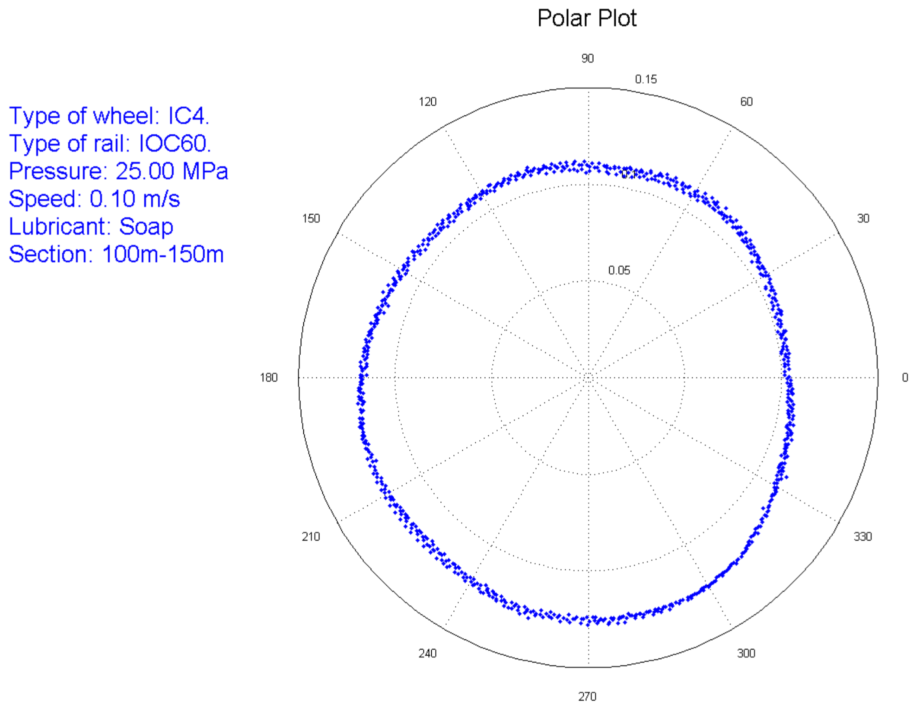


(b) Experiment with soap and IC4-pin at 25MPa

Figure 22: Experiments with soap at 25MPa



(a) Experiment with soap and IC3-pin at 25MPa

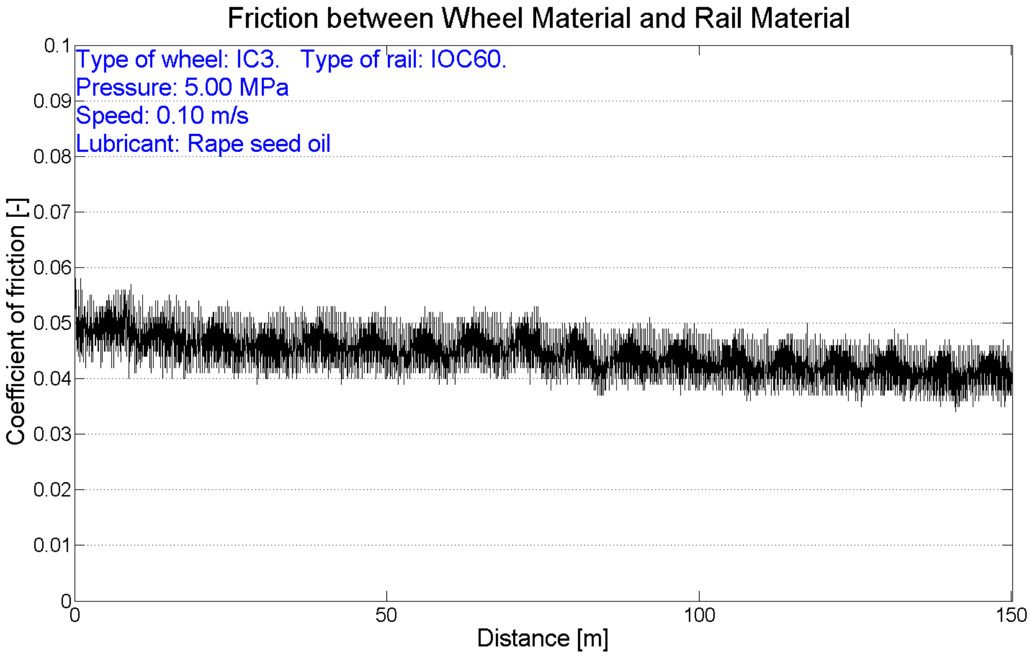


(b) Experiment with soap and IC4-pin at 25MPa

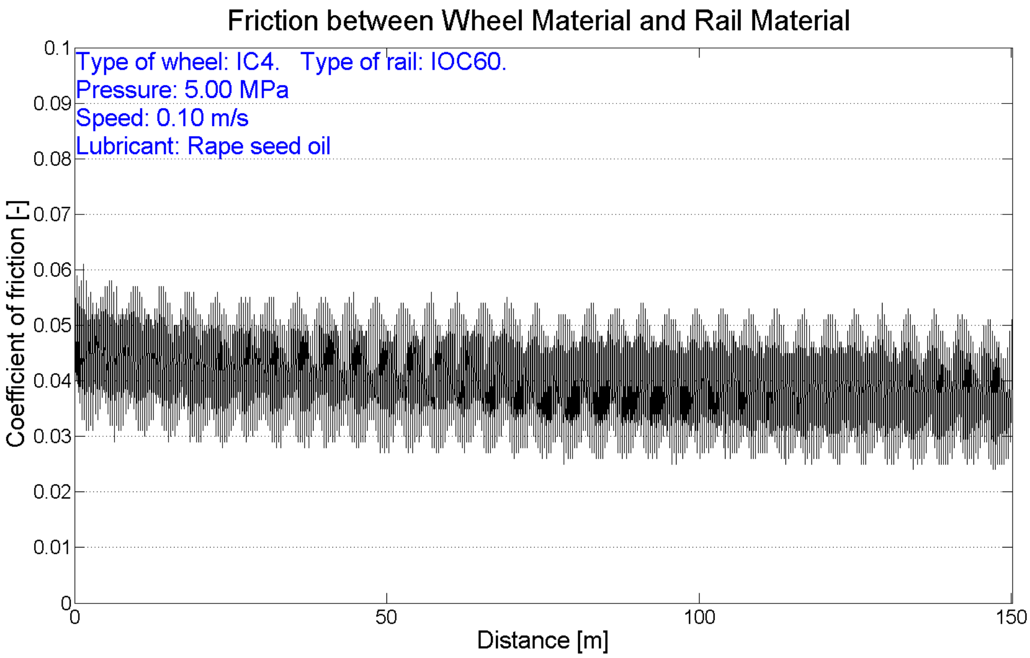
Figure 23: Experiments with soap at 25MPa

5.2.2 Experiments with rape seed oil.

The plots in this section generally show a lower coefficient of friction in the IC4 experiments than in the IC3 experiments. In addition to this the friction fluctuates more in the IC4 experiments than in the IC3 experiments.

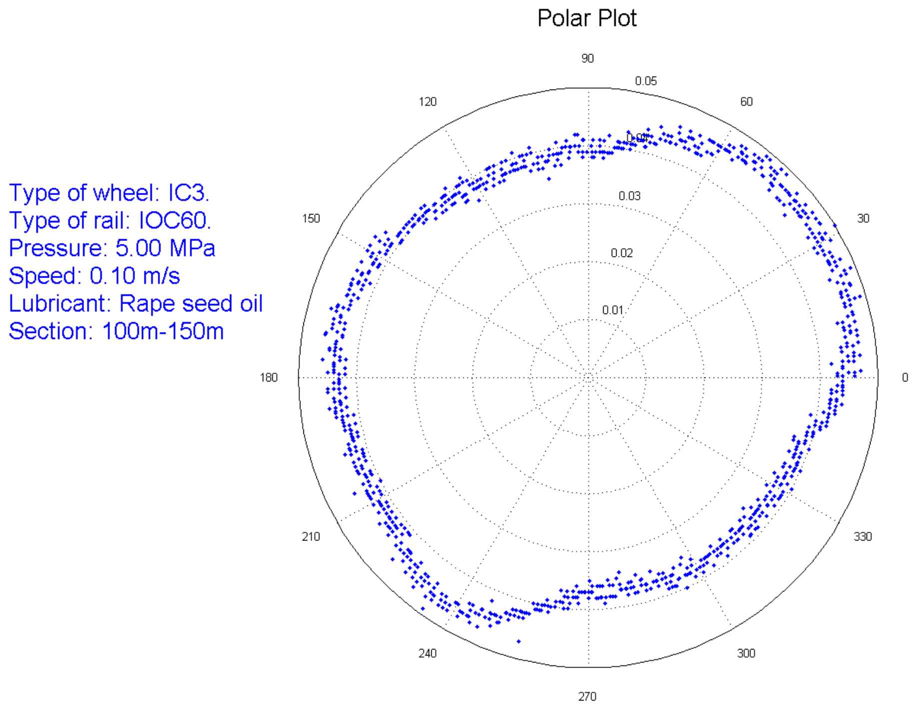


(a) Experiment with rape seed oil and IC3-pin at 5MPa

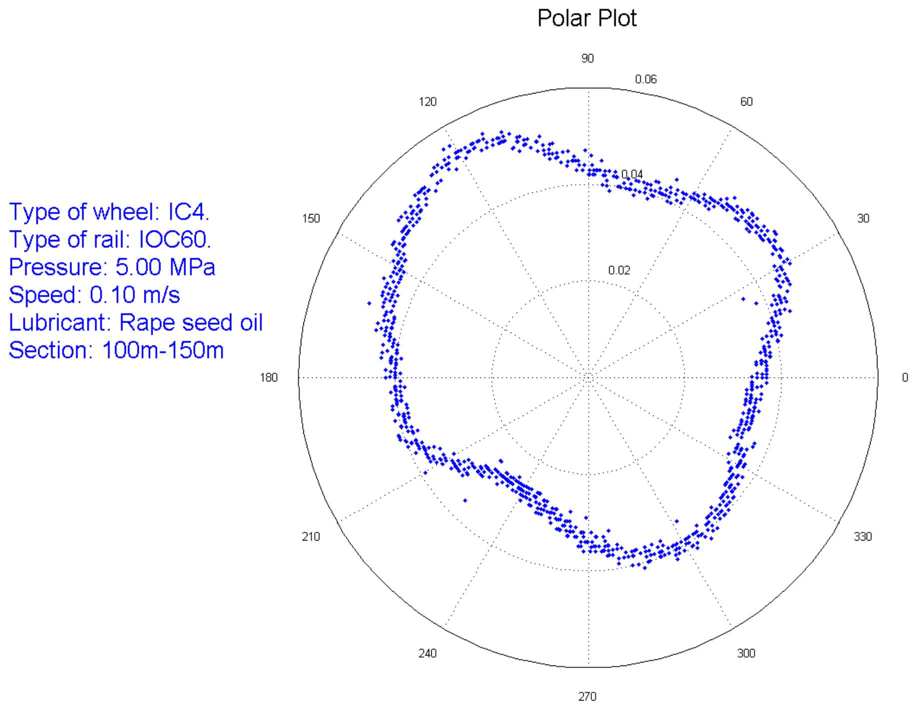


(b) Experiment with rape seed oil and IC4-pin at 5MPa

Figure 24: Experiments with rape seed oil at 5MPa

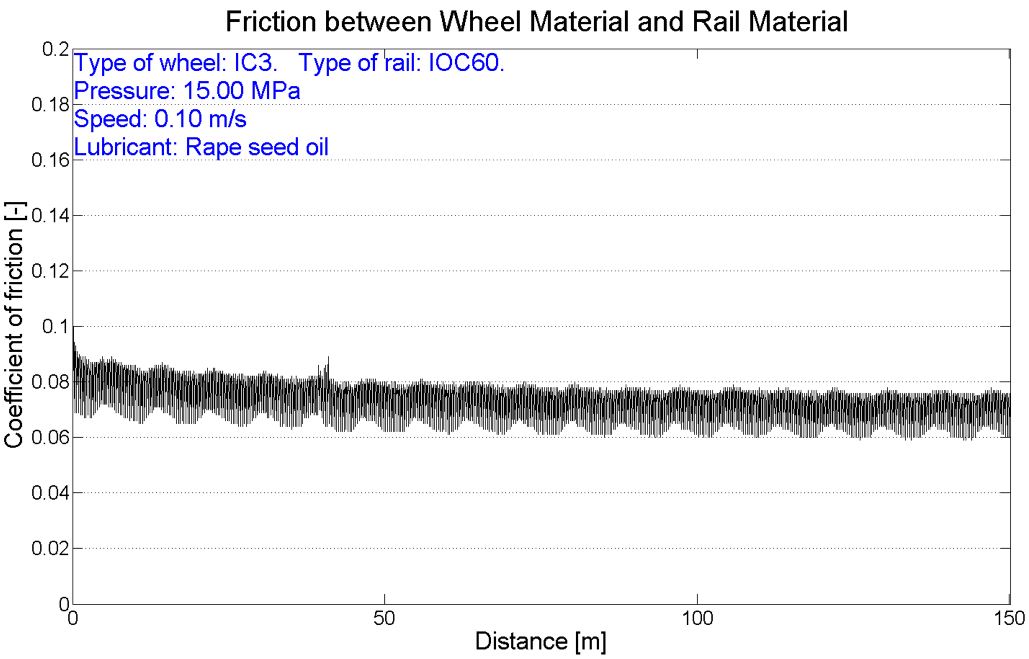


(a) Experiment with rape seed oil and IC3-pin at 5MPa

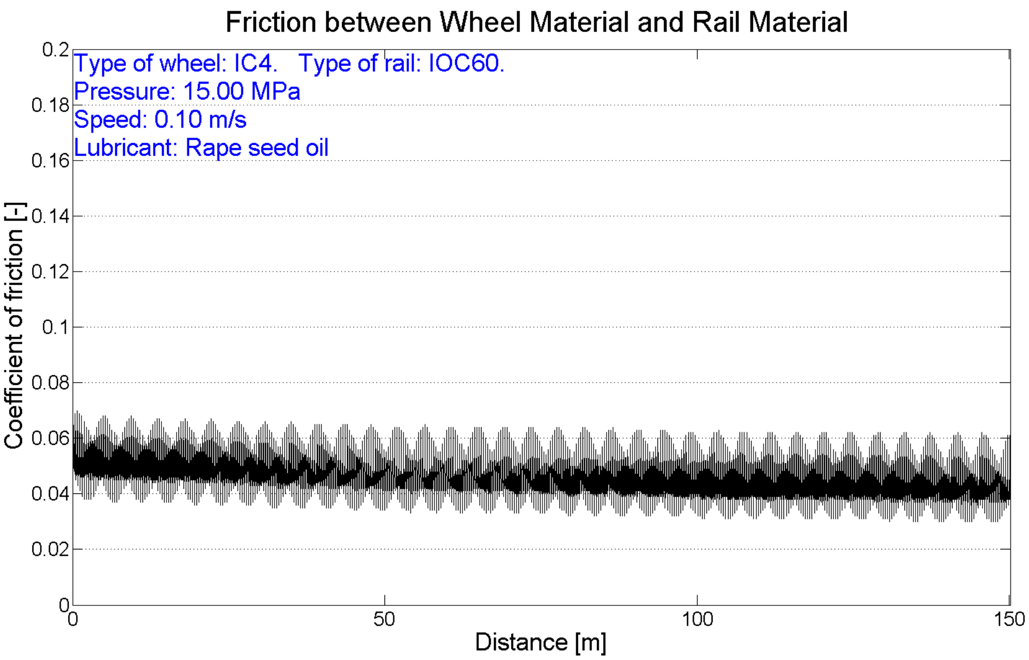


(b) Experiment with rape seed oil and IC4-pin at 5MPa

Figure 25: Experiments with rape seed oil at 5MPa

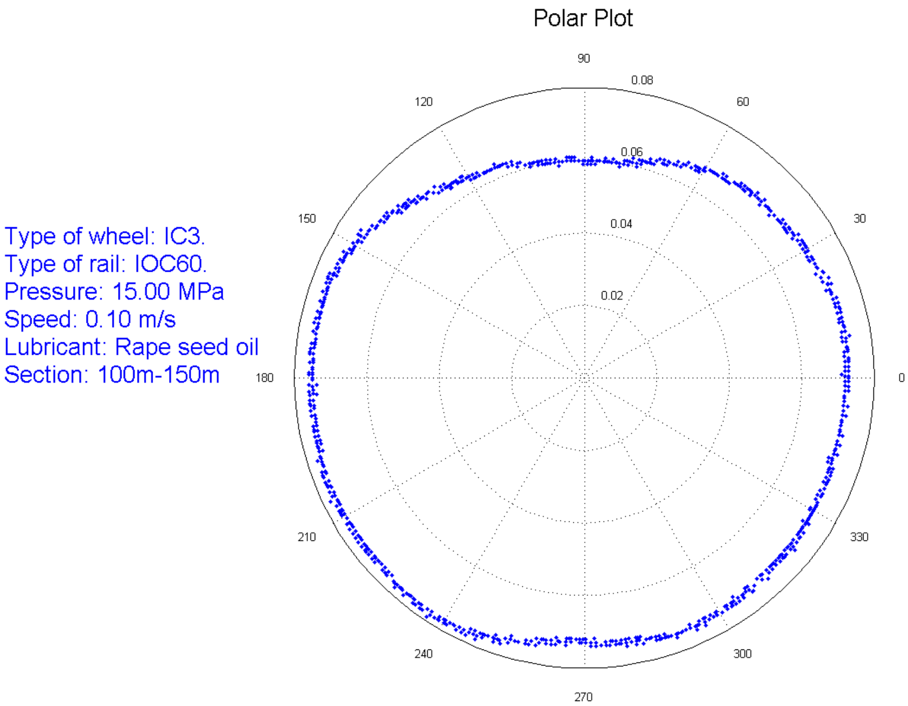


(a) Experiment with rape seed oil and IC3-pin at 15MPa

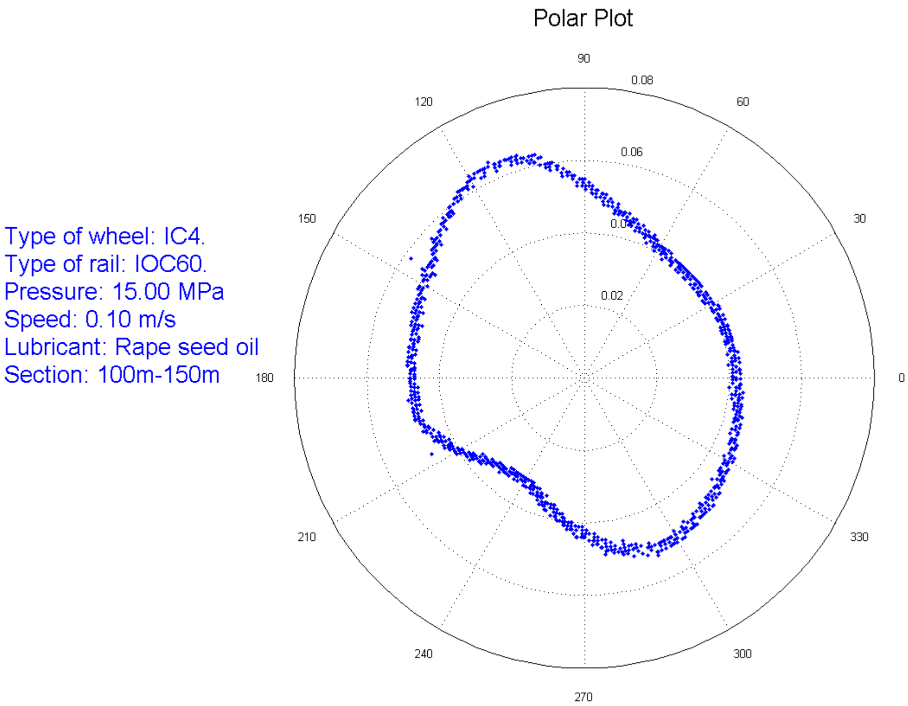


(b) Experiment with rape seed oil and IC4-pin at 15MPa

Figure 26: Experiments with rape seed oil at 15MPa

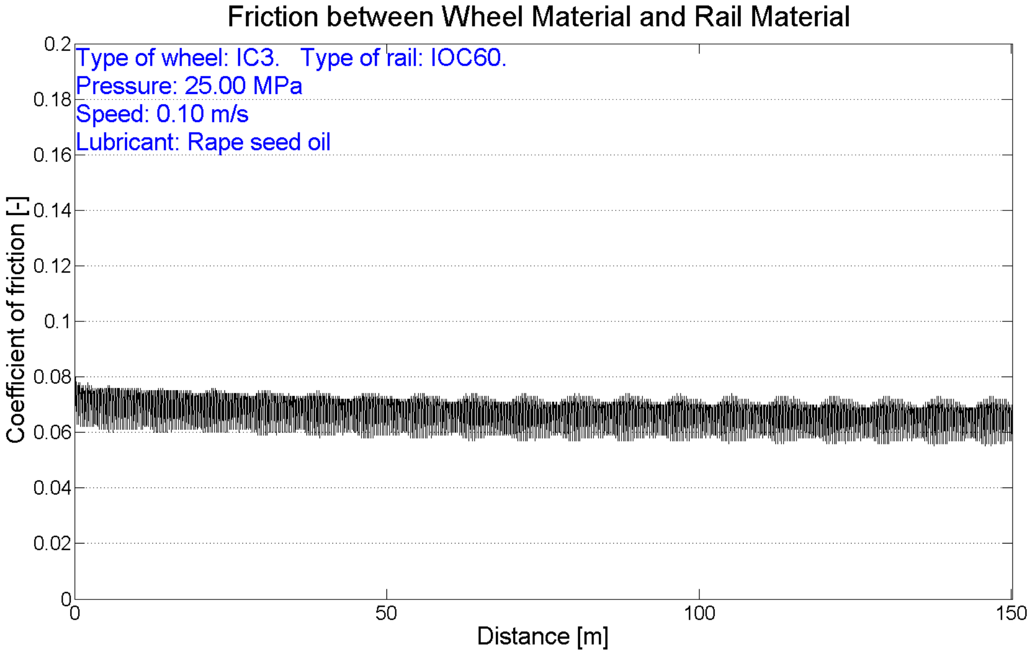


(a) Experiment with rape seed oil and IC3-pin at 15MPa

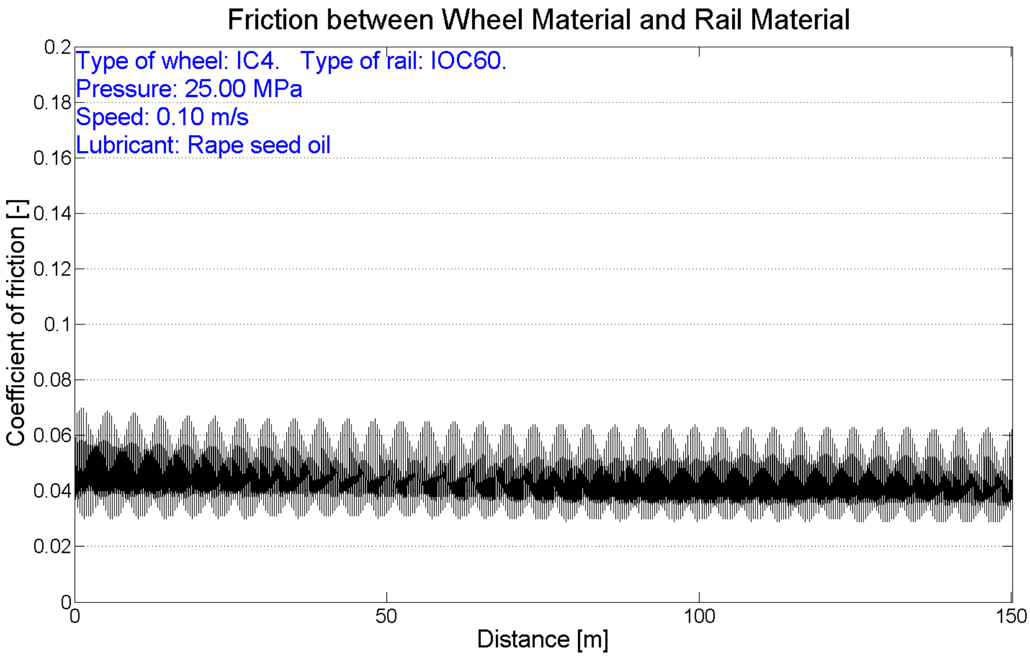


(b) Experiment with rape seed oil and IC4-pin at 15MPa

Figure 27: Experiments with rape seed oil at 15MPa

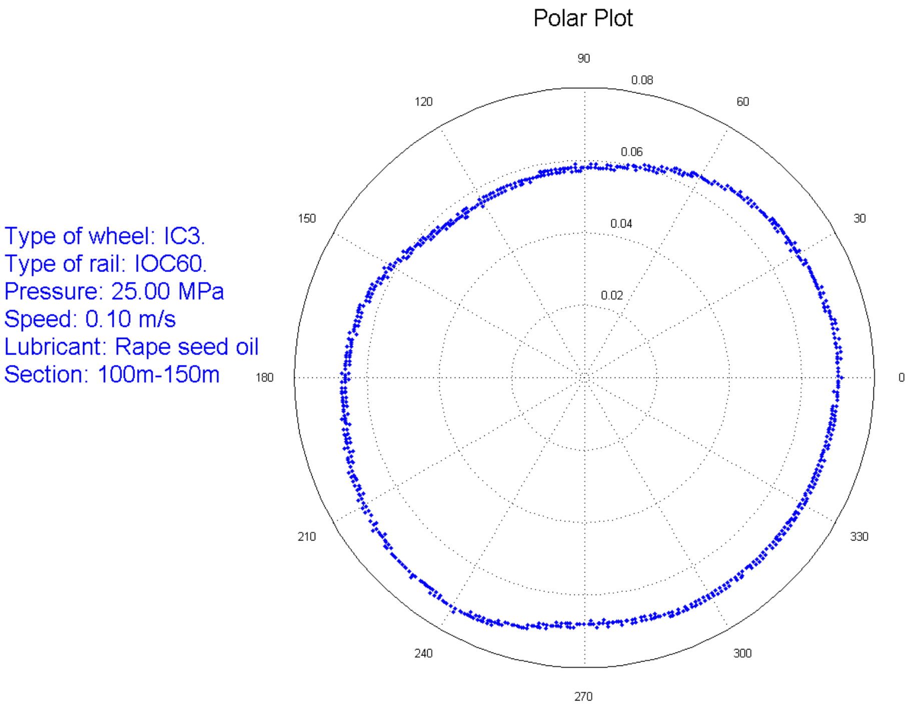


(a) Experiment with rape seed oil and IC3-pin at 25MPa

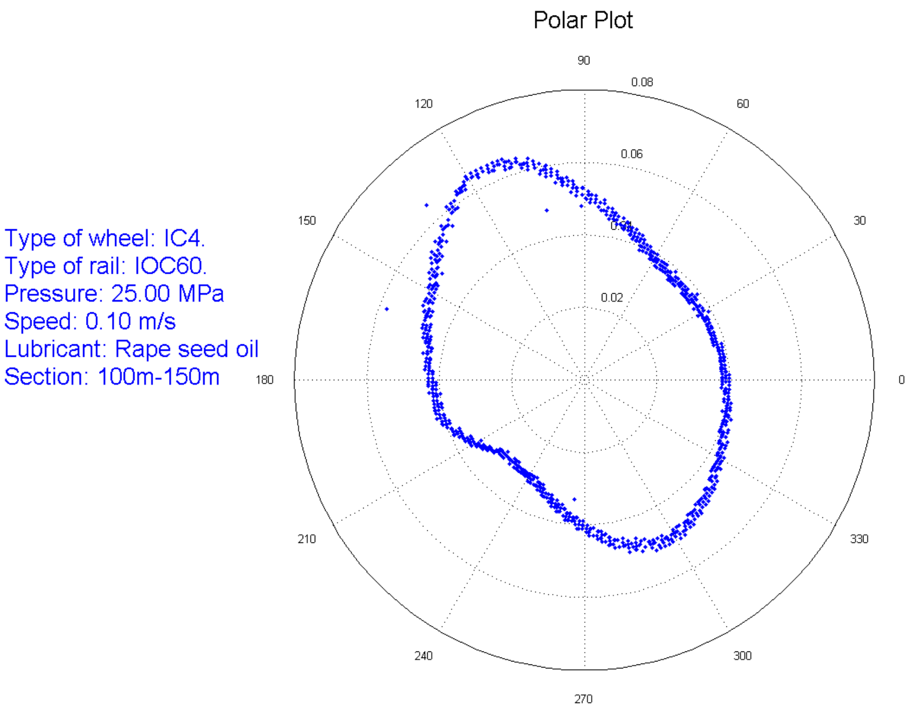


(b) Experiment with rape seed oil and IC4-pin at 25MPa

Figure 28: Experiments with rape seed oil at 25MPa

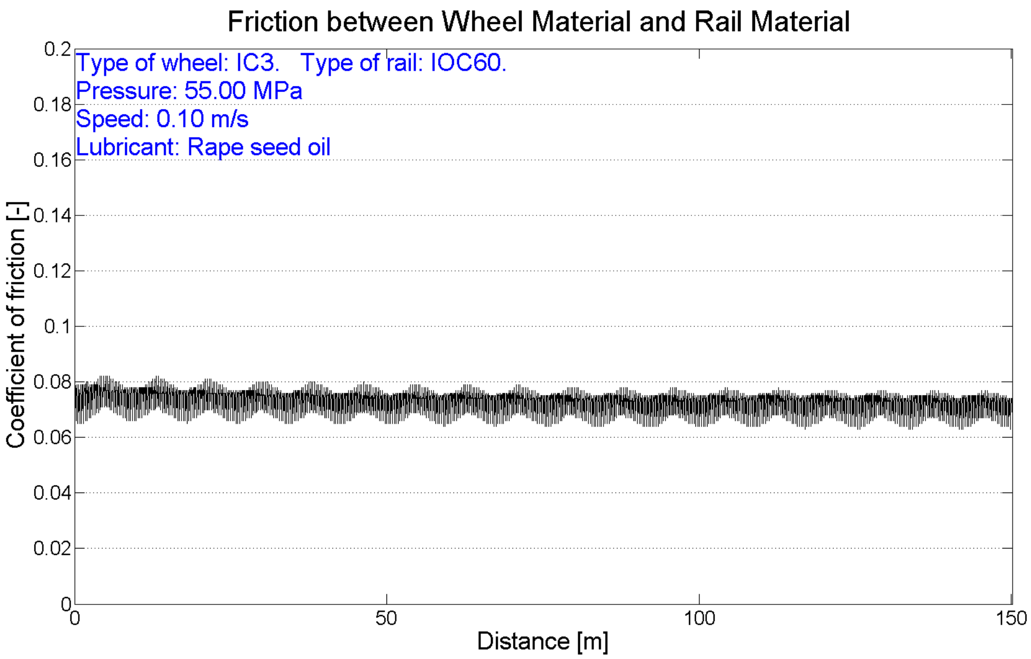


(a) Experiment with rape seed oil and IC3-pin at 25MPa

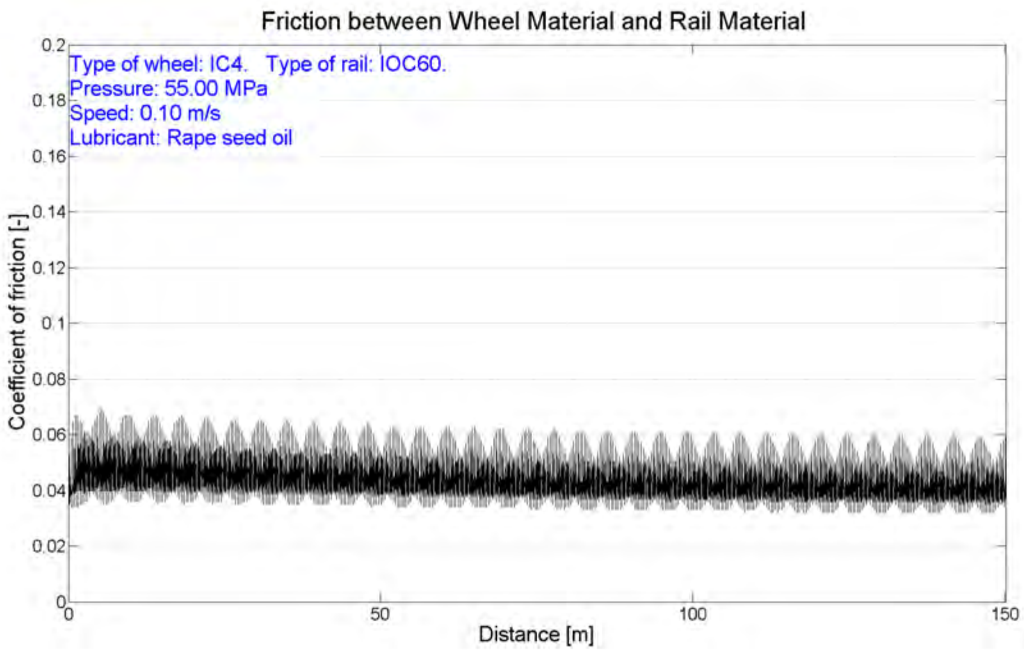


(b) Experiment with rape seed oil and IC4-pin at 25MPa

Figure 29: Experiments with rape seed oil at 25MPa

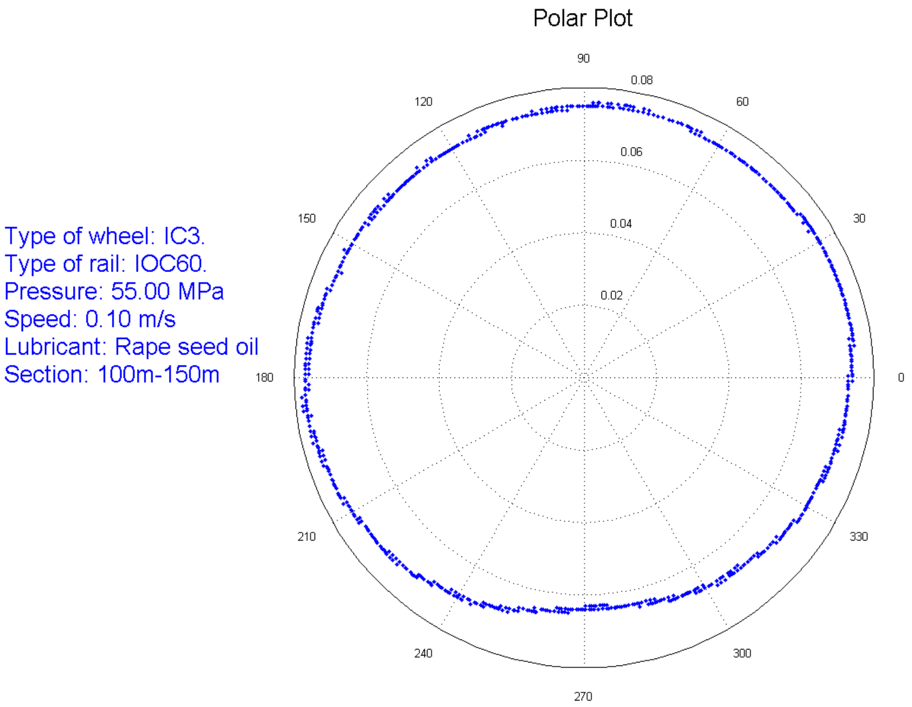


(a) Experiment with rape seed oil and IC3-pin at 55MPa

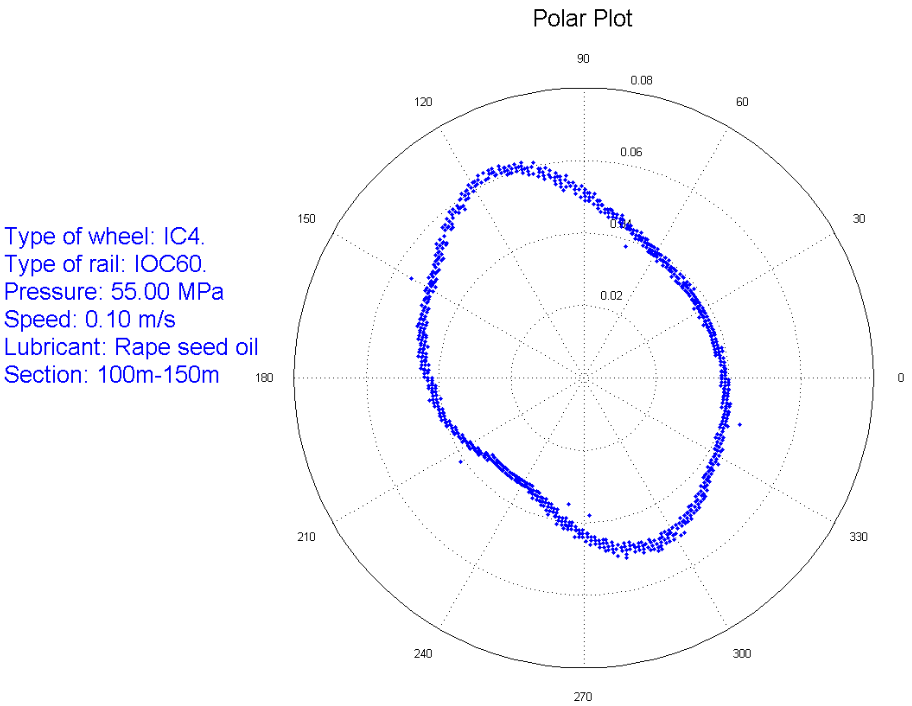


(b) Experiment with rape seed oil and IC4-pin at 55MPa

Figure 30: Experiments with rape seed oil at 55MPa

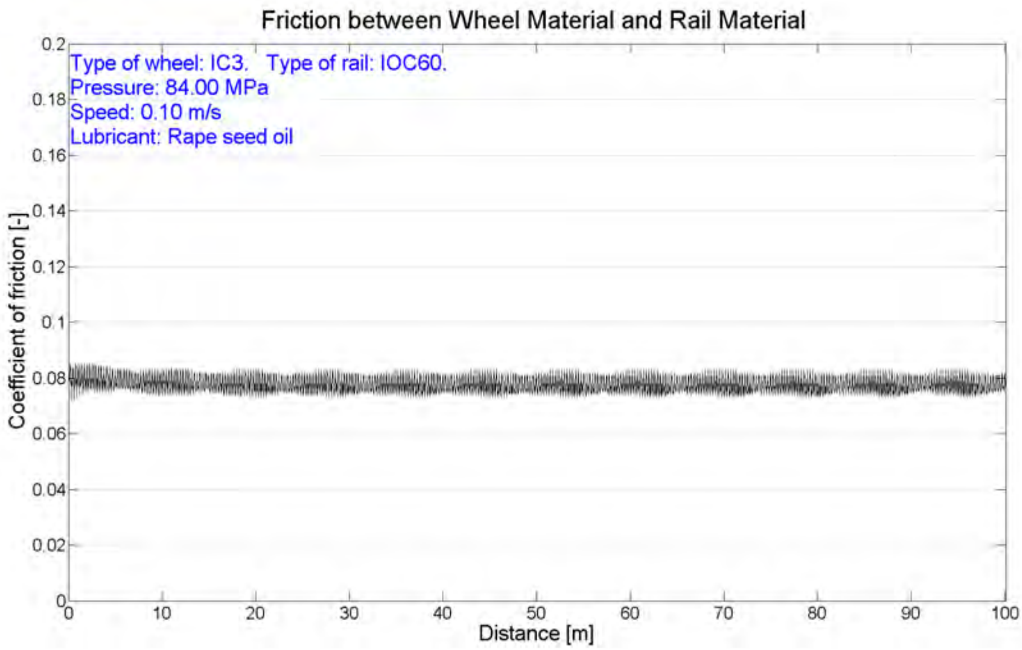


(a) Experiment with rape seed oil and IC3-pin at 55MPa

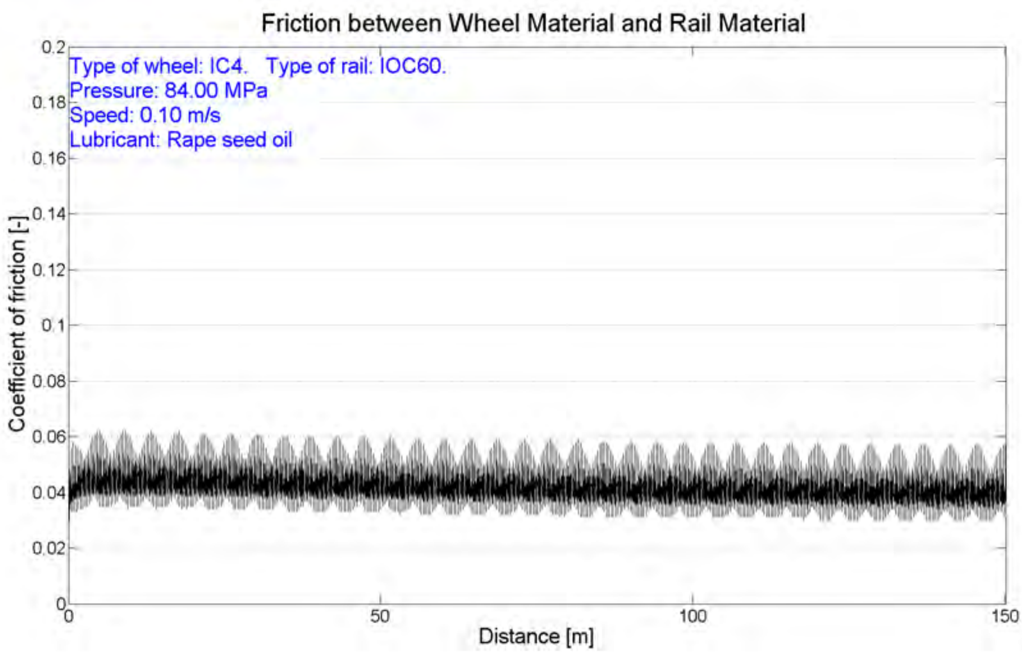


(b) Experiment with rape seed oil and IC4-pin at 55MPa

Figure 31: Experiments with rape seed oil at 55MPa

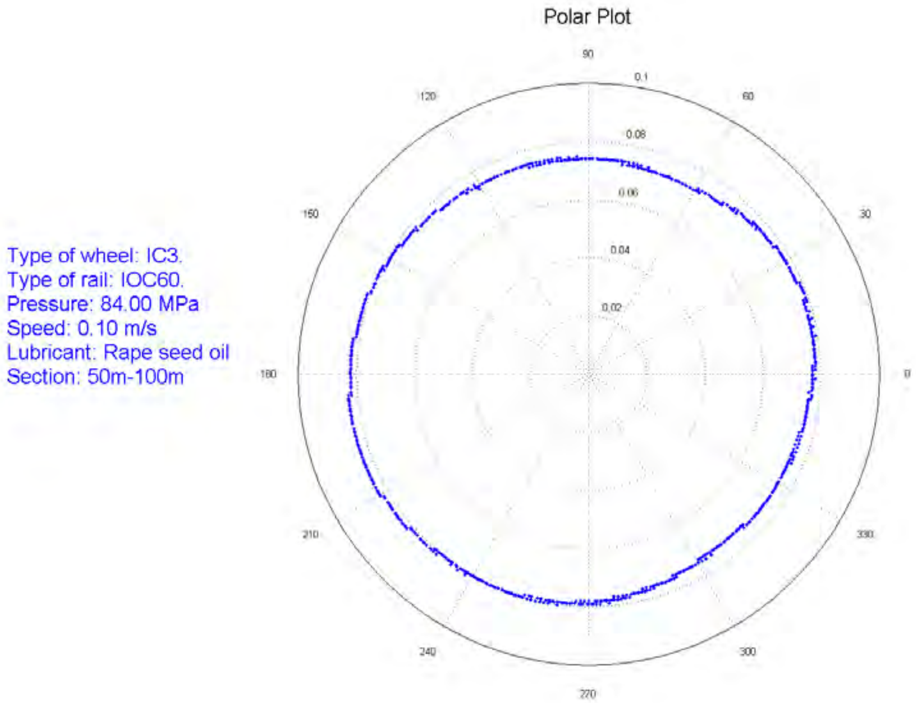


(a) Experiment with rape seed oil and IC3-pin at 84MPa

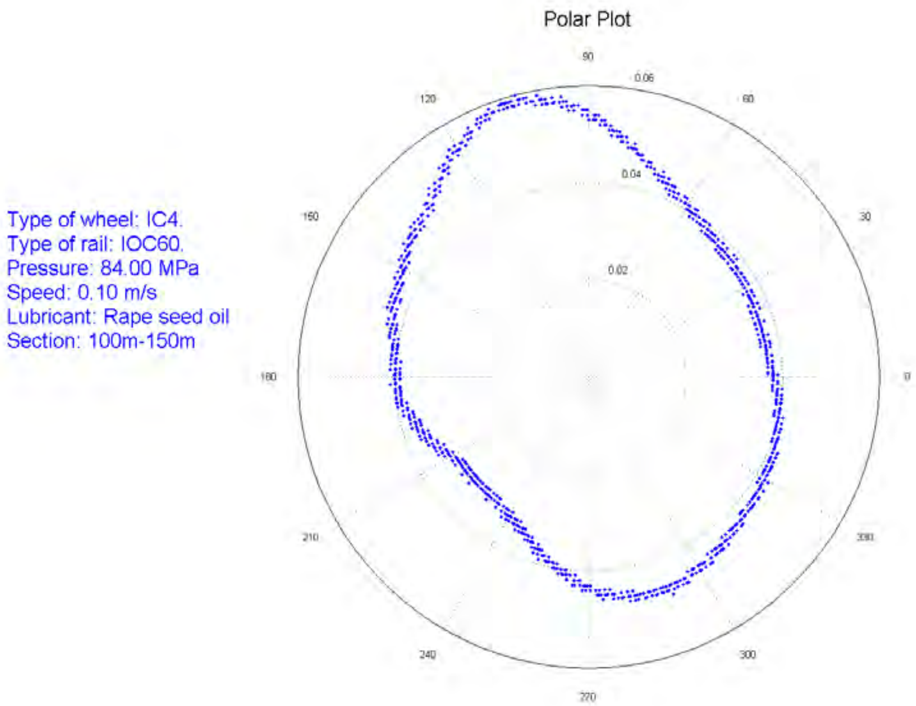


(b) Experiment with rape seed oil and IC4-pin at 84MPa

Figure 32: Experiments with rape seed oil at 84MPa



(a) Experiment with rape seed oil and IC3-pin at 84MPa



(b) Experiment with rape seed oil and IC4-pin at 84MPa

Figure 33: Experiments with rape seed oil at 84MPa

6. Conclusion.

A series of experiments were performed on a "Pin On Disc"-testrig, using soap and rape seed oil as lubricants.

In the first series of experiments where soap was used as lubricant, there was not any significant difference between the IC3 experiments and the IC4 experiments, regarding the coefficient of friction.
In the second series of experiments where soap was used as lubricant, the coefficient of friction fluctuates more, but the plots does not show a significant difference between the two wheel types, in terms of the coefficient of friction.

In the first series of experiments where rape seed oil was used, the coefficient of friction fluctuates significantly in both the IC3 experiments and the IC4 experiments. This is not a good basis for comparing the two wheel types.

In the second series of experiments where rape seed oil was used, the coefficient of friction is fairly steady regarding the IC3 experiments, whereas it fluctuates significantly in the IC4 experiments.
Again, this makes it difficult to compare the two wheel types on the basis of these particular experiments.

One possible explanation to these fluctuations could be that the disc has been ground prior to the experiments, meaning that the coefficient of friction may be higher where the direction, in which the disc has been ground, is perpendicular to the outer periphery of the disc.
This could be corrected by fine turning the disc instead of having it ground.

7. Appendix.

7.1 Experimental plans.

7.1.1 Experimental plan-1.

Study of Friction between Wheel and Track

Experimental Plan-1

Experiments with IC3 wheel material:

Wheel material: IC3
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures : 5Mpa, 15MPa, 25MPa
1 speed: 0,1m/s

Experiments with IC4 wheel material:

Wheel material: IC4
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures : 5Mpa, 15MPa, 25MPa
1 speed: 0,1m/s

Sequence.	Rail material	Wheel material	Speed	Lubrication	Pressure
8	UIC 60	IC3	0,1m/s	Soap	5MPa
5	UIC 60	IC3	0,1m/s	Soap	15MPa
3	UIC 60	IC3	0,1m/s	Soap	25MPa
1	UIC 60	IC4	0,1m/s	Soap	5MPa
2	UIC 60	IC4	0,1m/s	Soap	15MPa
6	UIC 60	IC4	0,1m/s	Soap	25MPa
4	UIC 60	IC3	0,1m/s	Oil	5MPa
10	UIC 60	IC3	0,1m/s	Oil	15MPa
7	UIC 60	IC3	0,1m/s	Oil	25MPa
9	UIC 60	IC4	0,1m/s	Oil	5MPa
11	UIC 60	IC4	0,1m/s	Oil	15MPa
12	UIC 60	IC4	0,1m/s	Oil	25MPa

7.1.2 Experimental plan-2.

Study of Friction between Wheel and Track

Experimental Plan-2

Experiments with IC3 wheel material:

Wheel material: IC3
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures using soap: 5Mpa, 15MPa, 25MPa
1 speed: 0,1m/s

Experiments with IC4 wheel material:

Wheel material: IC4
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures using soap: 5Mpa, 15MPa, 25MPa
1 speed: 0,1m/s

Sequence.	Rail material	Wheel material	Speed	Lubrication	Pressure
10	UIC 60	IC3	0,1m/s	Soap	5MPa
11	UIC 60	IC3	0,1m/s	Soap	15MPa
2	UIC 60	IC3	0,1m/s	Soap	25MPa
8	UIC 60	IC4	0,1m/s	Soap	5MPa
4	UIC 60	IC4	0,1m/s	Soap	15MPa
1	UIC 60	IC4	0,1m/s	Soap	25MPa
12	UIC 60	IC3	0,1m/s	Oil	5MPa
3	UIC 60	IC3	0,1m/s	Oil	15MPa
6	UIC 60	IC3	0,1m/s	Oil	25MPa
9	UIC 60	IC4	0,1m/s	Oil	5MPa
5	UIC 60	IC4	0,1m/s	Oil	15MPa
7	UIC 60	IC4	0,1m/s	Oil	25MPa

7.1.3 Experimental plan-3.

Study of Friction between Wheel and Track

Experimental Plan-3

Experiments with IC3 wheel material:

Wheel material: IC3
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures using soap: 5Mpa, 15MPa, 25MPa
9 different pressures using oil : 5Mpa, 15MPa, 25MPa, 35MPa, 45MPa, 55MPa, 65MPa, 75MPa, 84MPa
1 speed: 0,1m/s

Experiments with IC4 wheel material:

Wheel material: IC4
1 type of rail material: UIC 60
2 types of lubrication: Soap, Oil
3 different pressures using soap: 5Mpa, 15MPa, 25MPa
9 different pressures using oil : 5Mpa, 15MPa, 25MPa, 35MPa, 45MPa, 55MPa, 65MPa, 75MPa, 84MPa
1 speed: 0,1m/s

Sequence.	Rail material	Wheel material	Speed	Lubrication	Pressure
1	UIC 60	IC3	0,1m/s	Soap	5MPa
2	UIC 60	IC3	0,1m/s	Soap	15MPa
3	UIC 60	IC3	0,1m/s	Soap	25MPa
4	UIC 60	IC4	0,1m/s	Soap	5MPa
5	UIC 60	IC4	0,1m/s	Soap	15MPa
6	UIC 60	IC4	0,1m/s	Soap	25MPa
7	UIC 60	IC3	0,1m/s	Oil	5MPa
8	UIC 60	IC3	0,1m/s	Oil	15MPa
9	UIC 60	IC3	0,1m/s	Oil	25MPa
10	UIC 60	IC3	0,1m/s	Oil	35MPa
11	UIC 60	IC3	0,1m/s	Oil	45MPa
12	UIC 60	IC3	0,1m/s	Oil	55MPa
13	UIC 60	IC3	0,1m/s	Oil	65MPa
14	UIC 60	IC3	0,1m/s	Oil	75MPa
15	UIC 60	IC3	0,1m/s	Oil	84MPa
16	UIC 60	IC4	0,1m/s	Oil	5MPa
17	UIC 60	IC4	0,1m/s	Oil	15MPa
18	UIC 60	IC4	0,1m/s	Oil	25MPa
19	UIC 60	IC4	0,1m/s	Oil	35MPa
20	UIC 60	IC4	0,1m/s	Oil	45MPa
21	UIC 60	IC4	0,1m/s	Oil	55MPa
22	UIC 60	IC4	0,1m/s	Oil	65MPa
23	UIC 60	IC4	0,1m/s	Oil	75MPa
24	UIC 60	IC4	0,1m/s	Oil	84MPa

7.2 Wheel material.

Appendix I – Wheel Chemistry Table

WHEEL STEEL CHEMICAL ANALYSIS LEVELS

STANDARD	COUNTRY OF ORIGIN	GRADE	CARBON % (MAX)	SILICON % (MAX)	MANG. % (MAX)	PHOS. % (MAX)	SULP. % (MAX)	CHROME % (MAX)	COPPER % (MAX)	MOLYB. % (MAX)	NICKEL % (MAX)	VAN. % (MAX)	CR+MO+NI % (MAX)	HYDROGEN PPM (MAX) CAT1	CAT2
JIS E5402	JAPAN	C44	0.46	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
AAR M107*	N.AMERICA	L	0.47	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
BS5892:PT3	UK	R6T	0.48	0.40	0.75	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER6	0.48	0.40	0.75	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
JIS E5402	JAPAN	C48	0.50	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
GOST 10791	RUSSIA	GRADE 1	0.44/0.52	0.40/0.65	0.80/1.20	0.035	0.030	0.30	0.30	0.08	0.30	0.08/0.15	N/S	2.0	2.0
BS5892:PT3	UK	R7T	0.52	0.40	0.80	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER7	0.52	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
IRSS	INDIA	R19	0.52	0.15/0.40	0.60/0.80	0.030	0.030	0.25	0.28	0.06	0.25	0.05	0.50	3.0	3.0
JIS E5402	JAPAN	C51	0.54	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
VALDUNES	FRANCE	R8TUCS	0.54	0.30/1.10	0.60/1.10	0.020	0.005/0.020	0.30/0.50	0.30	0.08	0.30	0.06	0.65	2.0	2.5
FSR	FINLAND	ER8MOD	0.52/0.56	0.90/1.10	0.90/1.10	0.015	0.006	0.30	0.10	0.08	0.30	0.08	0.05	2.0	2.0
LUCCHINI	ITALY	SUPERLOS	0.49/0.56	0.60/1.10	0.60/1.10	0.015	0.020	0.30	0.30	0.08	0.30	0.08	0.05	1.8	1.8
BS5892:PT3	**UK**	**R8T**	**0.56**	**0.40**	**0.80**	**0.040**	**0.040**	**0.30**	**0.30**	**0.08**	**0.30**	**0.05**	**0.60**	**2.0#**	**2.0#**
EN13262	EUROPE	ER8	0.56	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
AAR M107*	N.AMERICA	A	0.47/0.57	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
JIS E5402	JAPAN	C55	0.58	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
BS5892:PT3	UK	R9T	0.60	0.40	0.80	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER9	0.60	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
GOST 10791	RUSSIA	GRADE 2	0.55/0.65	0.22/0.45	0.50/0.90	0.035	0.030	0.30	0.30	0.08	0.30	0.10	N/S	2.0	2.0
TB/T 2708	CHINA	CL60	0.55/0.65	0.17/0.37	0.50/0.80	0.040	0.040	0.25	0.25	N/S	0.25	N/S	0.50	N/S	N/S
GOST 10791	RUSSIA	GRADE 3	0.58/0.67	0.22/0.45	0.50/0.90	0.035	0.030	0.30	0.30	0.08	0.30	0.08/0.15	N/S	2.0	2.0
JIS E5402	JAPAN	C64	0.67	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
AAR M107*	N.AMERICA	B	0.57/0.67	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
IRSS	INDIA	R34	0.57/0.67	0.15 MIN	0.60/0.90	0.030	0.030	0.25	0.28	0.06	0.25	0.05	0.50	2.5	2.5
AAR M107*	N.AMERICA	C	0.67/0.77	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
JIS E5402	JAPAN	C74	0.77	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S

LIMITS SPECIFIED ARE MAXIMUM UNLESS SPECIFIED OTHERWISE

2PPM LEVEL AS REQUIRED BY RAILWAY GROUP STANDARD GM/RT2466

* AAR SPECIFICATION ALSO HAS AL 0.060 MAX, TITANIUM 0.03 MAX AND NIOBIUM 0.05 MAX.

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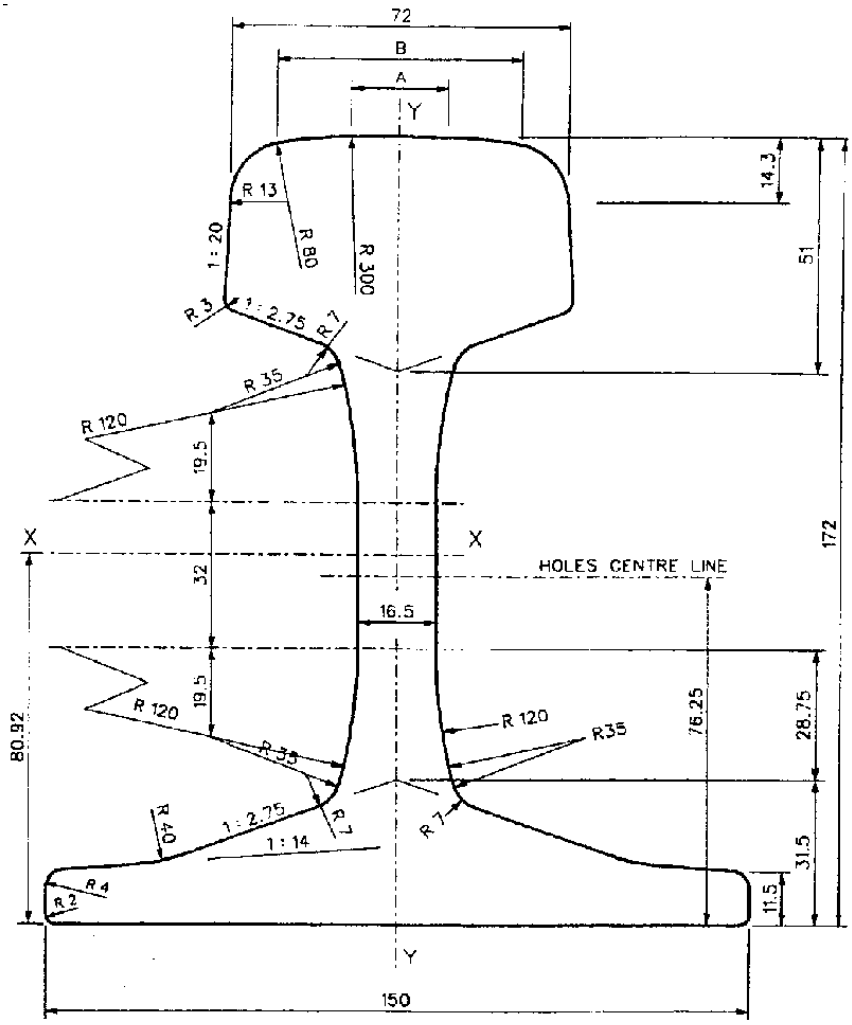
Figure 34: Table of wheel materials.

7.3 Rail profile.



Full description UIC 60 Rolled Flat Bottom Section (CEN designation: CEN 60E1)
Weight 60.2kg/m.
Cross-sectional area 7670sq.mm.

Indicative Dimensions:
A - 20.456mm
B - 52.053mm

RAIL SECTION - UIC 60

Figure 35: Drawing of UIC60 rail profile.

7.4 Working drawing of pin.

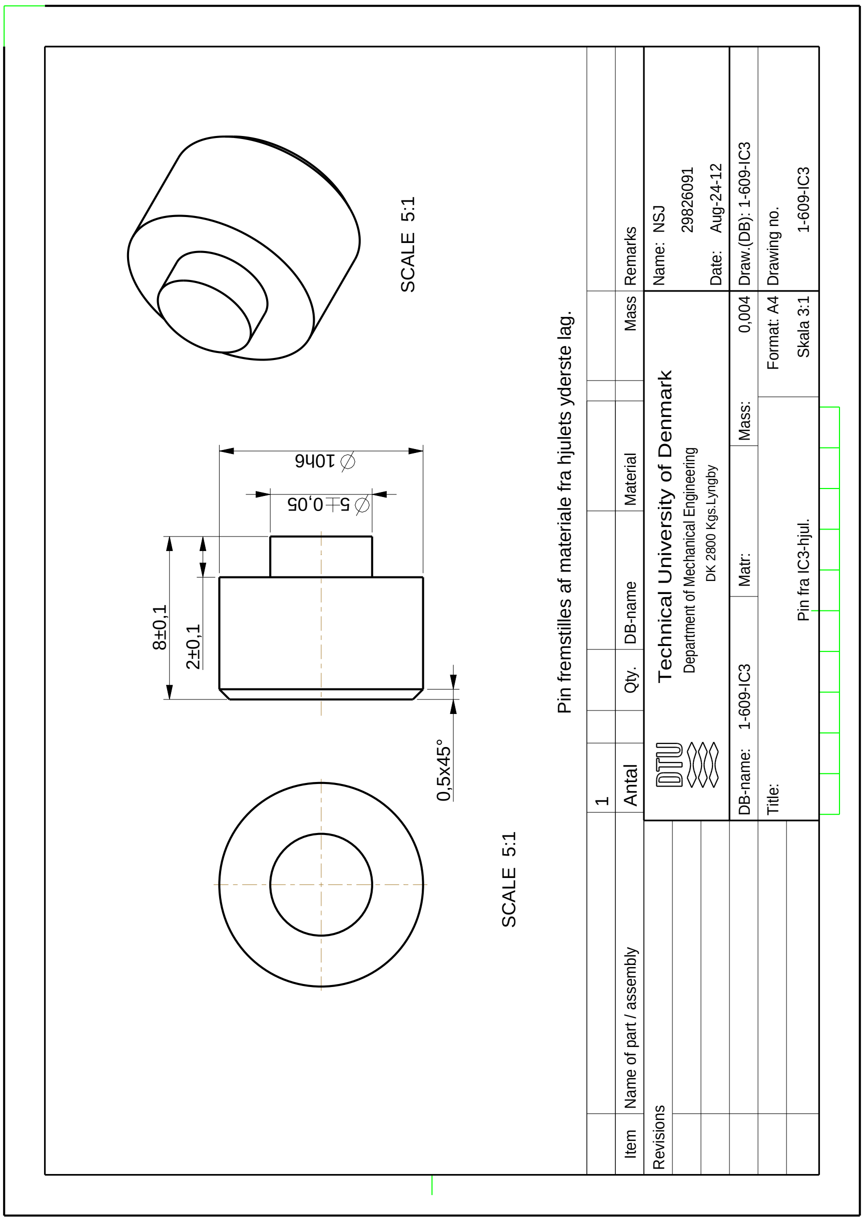


Figure 36: Working drawing of pin.

7.5 Working drawing of disc.

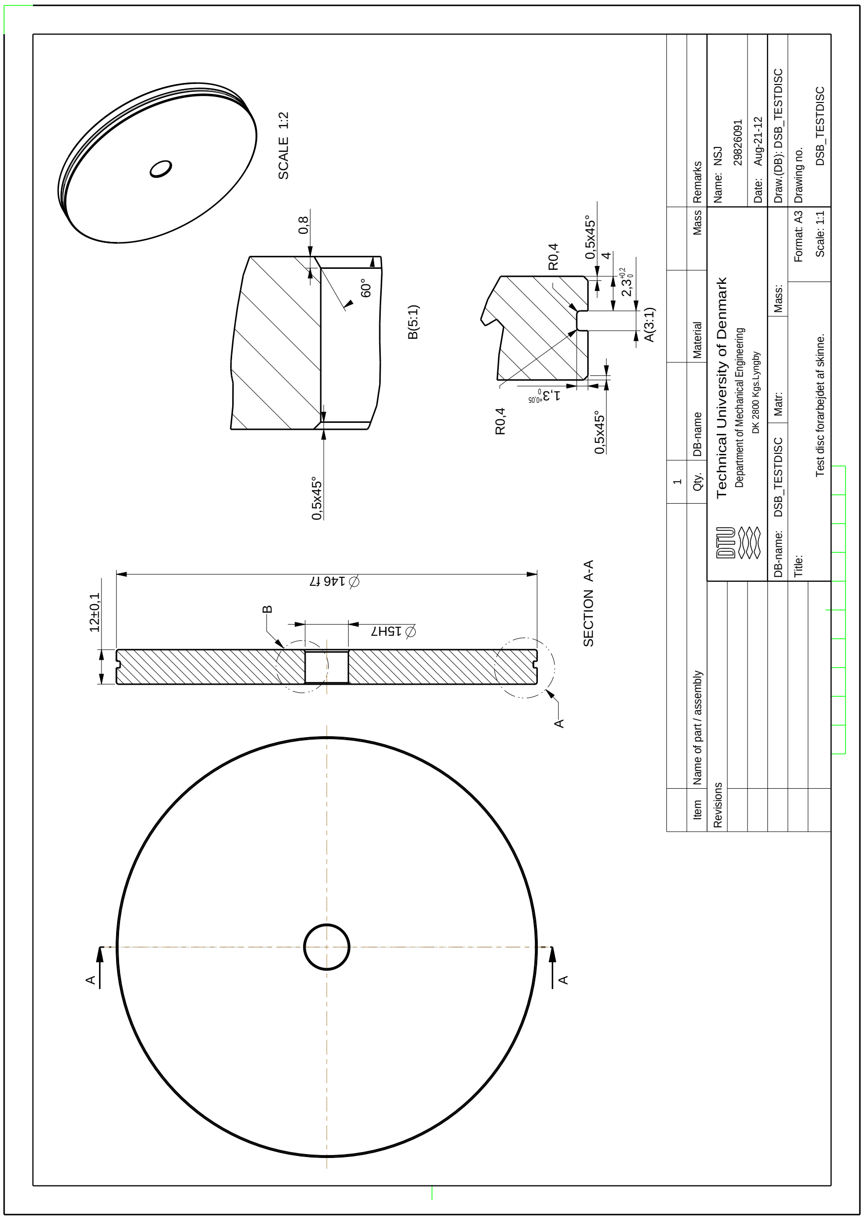


Figure 37: Working drawing of disc.

7.6 Datasheet (Soap).

Udarbejdet på baggrund af EU forordningen 1907/2006 (REACH)

knudedan.dk

SIKKERHEDSDATABLAD

1.1. Produktidentifikator

Handelsnavn
PLEJEVASK med voks
Produkt nr.
3006
REACH registreringsnummer
Ikke anvendelig
Andre produktidentifikatorer
PR-nr: 109787

1.2. Relevante identificerede anvendelser for stoffet eller blandingen samt anvendelser, der frarådes

Relevante identificerede anvendelser for stoffet eller blandingen
Gulvvaskemiddel med voks
Den fulde ordlyd af evt. nævnte identificerede anvendelseskategorier findes i punkt 16.

1.3. Nærmere oplysninger om leverandøren af sikkerhedsdatabladet

Firmanavn og adresse
Knud E. Dan A/S
Lunikvej 40
DK 2670
tlf: +45 43692422
fax: +45 43690578
Kontaktperson
Lars Bøgeholm
E-mail
lbj@knudedan.dk
SDS udarbejdet den
31-01-2012
SDS Version
1.0

1.4. Nødtelefon
Kontakt Giftlinien på tlf.nr.: 82 12 12 12 (åbent 24 timer i døgnet). Se punkt 4 om førstehjælp.

PUNKT 2: Fareidentifikation

2.1. Klassificering af stoffet eller blandingen
Produktet er ikke klassificeret som farligt.

2.2. Mærkningselementer

Farepiktogram
-
Risiko m.v.
-
Oplysningspligtige indholdsstoffer

Sikkerhed	Generelt	-
	Forebyggelse	-
	Reaktion	-
	Opbevaring	-
	Bortskaffelse	-

2.3. Andre farer

Anden mærkning
Sikkerhedsdatablad kan på anmodning rekvireres. Kodenummer (1993): 00-1

Andet
-
VOC

PLEJEVASK med voks 1/6

Udarbejdet på baggrund af EU forordningen 1907/2006 (REACH)

-

PUNKT 3: Sammensætning af/oplysning om indholdsstoffer

3.1/3.2. Stoffer

NAVN:	Larylethersulfat
IDENTIFIKATIONSNUMRE:	CAS-nr: 68585-34-2 EF-nr: 500-223-8
INDHOLD:	1-5%
DSD KLASSIFICERING:	Xi;R36/38
CLP KLASSIFICERING:	Skin Irrit. 2, Eye Irrit. 2 H315, H319

(*) Den fulde ordlyd af H/R-sætningerne findes i punkt 16. Arbejdshygiejniske grænseværdier er nævnt i punkt 8, såfremt de er tilgængelige.

Andre oplysninger

5 - 15%: sæbe
0 - 5%: anioniske overfladeaktive stoffer, nonioniske overfladeaktive stoffer, Linalool (PARFUME), 2,2',2''-(hexahydro-1,3,5-triazin-1,3,5-triyl)triethanol, Benziothiazolinone, parfume

PUNKT 4: Førstehjælpsforanstaltninger

4.1. Beskrivelse af førstehjælpsforanstaltninger

Generelt

Ved uheld: Kontakt læge eller skadestue - medbring etiketten eller dette sikkerhedsdatablad. Lægen kan rette henvendelse til Arbejds- og miljømedicinsk klinik, Bispebjerg Hospital, tlf. 35 31 60 60. Ved vedvarende symptomer eller ved tvivl om den tilskadekomnes tilstand skal der søges lægehjælp. Giv aldrig en bevidstløs person vand eller lignende.

Indånding

Ikke relevant.

Hudkontakt

Ikke relevant.

Øjenkontakt

Fjern evt. kontaktlinser. Skyl øjnene med rigelige mængder vand (20-30 °C) indtil evt. irritation ophører og mindst i 15 minutter. Ved fortsat irritation skal der søges lægehjælp.

Indtagelse

Giv personen rigeligt at drikke og personen under opsyn. Ved ildebefindende: Kontakt omgående læge og medbring dette sikkerhedsdatablad eller etiketten fra produktet.
Fremkalde ikke opkastning, medmindre lægen anbefaler det. Sænk hovedet, således at evt. opkast ikke vil løbe tilbage i munden og halsen.

Forbrænding

Skyl med rigelige mængder vand indtil smerten ophører og fortsæt derefter i 30 min.

4.2. Vigtigste symptomer og virkninger, både akutte og forsinkede

Ingen særlige

4.3. Angivelse af om øjeblikkelig lægehjælp og særlig behandling er nødvendig

Ingen særlige

Oplysning til lægen

Medbring dette sikkerhedsdatablad.

PUNKT 5: Brandbekæmpelse

5.1. Slukningsmidler

Anbefalet: alkoholbestandigt skum, kulsyre, pulvere, vandtåge.
Vandstråle bør ikke anvendes, da det kan sprede branden.

5.2. Særlige farer i forbindelse med stoffet eller blandingen

Ingen særlige

5.3. Anvisninger for brandmandskab

Normal indsatsbeklædning og fuld åndedrætsbeskyttelse. Ved direkte kontakt med kemikaliet kan indsatsleder kontakte kemikalieberedskabsvagten på telefon 45 90 60 00 (åbent 24 timer i døgnet), med henblik på yderligere rådgivning.

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PUNKT 6: Forholdsregler over for udslip ved uheld

6.1. Personlige sikkerhedsforanstaltninger, personlige værnemidler og nødprocedurer
Ingen særlige krav.
6.2. Miljøbeskyttelsesforanstaltninger
Ingen særlige krav.
6.3. Metoder og udstyr til inddæmning og oprensning
Brug sand, kattegrus, savsmuld eller universalbindemiddel til opsamling af væsker. Rengøring foretages for så vidt muligt med rengøringsmidler. Opløsningsmidler bør undgås.
6.4. Henvisning til andre punkter
Se afsnittet "Forhold vedrørende bortskaffelse" om håndtering af affald. Se afsnittet om "Eksponeringskontrol/personlige værnemidler" for beskyttelsesforanstaltninger.

PUNKT 7: Håndtering og opbevaring

7.1. Forholdsregler for sikker håndtering
Se afsnittet "Eksponeringskontrol/personlige værnemidler" for oplysning om personlig beskyttelse.
7.2. Betingelser for sikker opbevaring, herunder eventuel uforenelighed
Opbevares altid i beholdere af samme materiale som den originale. Produktet er ikke kategoriseret som brandfarligt
Lagertemperatur
5 - 25 °C
7.3. Særlige anvendelser
Produktet bør kun bruges til anvendelser beskrevet i punkt 1.2.

PUNKT 8: Eksponeringskontrol/personlige værnemidler

8.1. Kontrolparametre

Grænseværdier
Ingen data
DNEL / PNEC
Ingen data tilgængelige
8.2. Eksponeringskontrol
Ingen kontrol nødvendig under forudsætning af, at produktet anvendes normalt.
Generelle forholdsregler
Udvis alm. arbejdshygiejne.
Eksponeringsscenarier
Såfremt der findes et bilag til dette sikkerhedsdatablad, skal de her i angivne eksponeringsscenarier efterkommes.
Eksponeringsgrænse
Der forefindes ikke eksponeringsgrænser for indholdsstoffer i produktet.
Tekniske tiltag
Udvis almindelig forsigtighed ved brug af produktet. Undgå indånding af gas og støv.
Hygiejniske foranstaltninger
Udvis almindelig forsigtighed ved brug af produktet.
Foranstaltninger til begrænsning af eksponering af miljøet
Ingen særlige krav.
Personligt værneudstyr
-
Generelt
Såfremt arbejdsprocessen er omfattet af bekendtgørelsen om arbejde med kodenummererede produkter (Arbejdstilsynets Bekendtgørelse nr. 302/1993), skal værnemidler vælges i overensstemmelse hermed. Se evt. produktets kodenummer i afsnittet om 'Fareidentifikation'.
Luftvejene
Ingen særlige krav.
Hud og krop
Ingen særlige krav.
Hænder

Udarbejdet på baggrund af EU forordningen 1907/2006 (REACH)

Ingen særlige krav.

Øjne

Ingen særlige krav.

PUNKT 9: Fysisk-kemiske egenskaber

9.1. Oplysninger om grundlæggende fysiske og kemiske egenskaber

Fysisk tilstand	Farve	Lugt	pH	Viskositet	Massefylde (g/cm3)
Flydende	Grøn	Karakteristisk	10	-	1,02

Tilstandsændring og dampe

Smeltepunkt (°C)	Kogepunkt (°C)	Damptryk (mm Hg)
-	-	-

Data for brand- og eksplosionsfare

Flammepunkt (°C)	Antændelighed (°C)	Selvantændelighed (°C)
-	-	-

Eksplosionsgrænser (Vol %)	Oxiderende egenskaber
-	-

Opløselighed

Opløselighed i vand	n-octanol/vand koefficient
Opløselig	-

9.2. Andre oplysninger

Opløselighed i fedt	Andet
-	N/A

PUNKT 10: Stabilitet og reaktivitet

10.1. Reaktivitet

Ingen data

10.2. Kemisk stabilitet

Produktet er stabilt under de betingelser, som er angivet i afsnittet "Håndtering og opbevaring".

10.3. Risiko for farlige reaktioner

Ingen særlige

10.4. Forhold, der skal undgås

Bør ikke udsættes for direkte opvarmning (fx solbestråling).

10.5. Materialer, der skal undgås

Stærke syrer, stærke baser, stærke oxidationsmidler og stærke reduktionsmidler

10.6. Farlige nedbrydningsprodukter

Produktet nedbrydes ikke ved brug til anvendelser angivet i sektion 1.

PUNKT 11: Toksikologiske oplysninger

11.1. Oplysninger om toksikologiske virkninger

Akut toksicitet

Substans	Art	Test	Eksponeringsvej	Resultat
Ingen data tilgængelige				

Langtidsvirkninger

Ingen særlige

PUNKT 12: Miljøoplysninger

12.1. Toksicitet

Substans	Art	Test	Testens varighed	Resultat
Ingen data tilgængelige				

12.2. Persistens og nedbrydelighed

Substans	Nedbrydelighed i vandmiljøet	Test	Resultat
Ingen data tilgængelige			

12.3. Bioakkumuleringspotentiale

Substans	Potentiel bioakkumulerbar	LogPow	BCF
Ingen data tilgængelige			

Udarbejdet på baggrund af EU forordningen 1907/2006 (REACH)

12.4. Mobilitet i jord
Ingen data
12.5. Resultater af PBT- og vPvB-vurdering
Ingen data
12.6. Andre negative virkninger
Ingen særlige

PUNKT 13: Forhold vedrørende bortskaffelse

13.1. Metoder til affaldsbehandling
Produktet er omfattet af reglerne om farligt affald.
Affald

EAK-kode	Kemikalieaffaldsgruppe:
20 01 30	

Særlig mærkning
-
Forurenet emballage
Emballager, med restindhold af produktet, bortskaffes efter samme betingelser som produktet.

PUNKT 14: Transportoplysninger

Ikke farligt gods i henhold til ADR og IMDG.
14.1 – 14.4

ADR/RID	UN-nummer	UN-forsendelsesbetegnelse (UN proper shipping name)	Transportfareklasse	Emballagegruppe	Bemærkninger

IMDG	UN-no.	Proper Shipping Name	Class	PG*	EmS	MP**	Hazardous constituent

14.5. Miljøfarer
-
14.6. Særlige forsigtighedsregler for brugeren
-
14.7. Bulktransport i henhold til bilag II i MARPOL 73/78 og IBC-koden
Ingen data
(*) Packing group
(**) Marine pollutant

PUNKT 15: Oplysninger om regulering

15.1. Særlige bestemmelser/særlig lovgivning for stoffet eller blandingen med hensyn til sikkerhed, sundhed og miljø

Anvendelsesbegrænsninger
-
Krav om særlig uddannelse
-
15.2. Kemikaliesikkerhedsvurdering
Nej

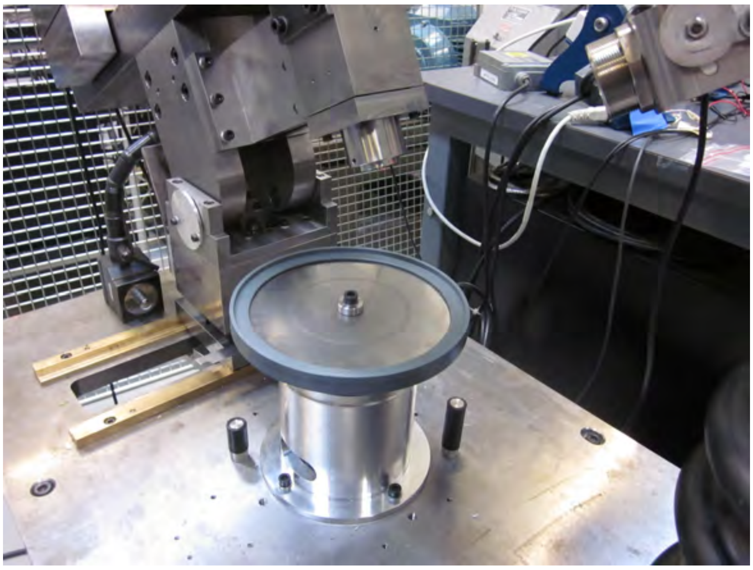
PUNKT 16: Andre oplysninger

Kilder

Preliminary Study of Friction between Wheel and Track.

Commissioned by DSB.

March 1, 2013



Experiments conducted by:
Niels Steenfeldt Jensen
Laboratory engineer
Departement of Mechanical Engineering
Technical University of Denmark
Telephone: 45 25 55 65
Email: nstje@mek.dtu.dk

Niels Steenfeldt Jensen Peder Klit

Contents

1. Preliminary.

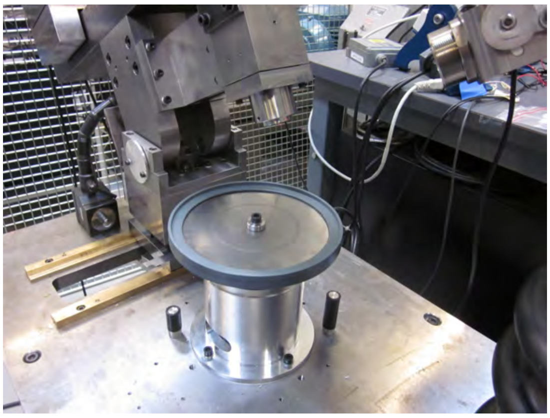
A series of experiments are to be conducted, in order to study the friction between wheel and rail.
The experiments are carried out at different loads and using different types of lubrication.
For use in the experiments, "Banedanmark" has provided a section from both the IC3- and IC4-wheel, and "DSB" has provided a piece of rail.
The experiments are carried out using a "Pin on Disc" test rig.

2. Description of test rig.

The experiments are performed using a "Pin on Disc" test rig (See figure 1). The principle of operation involves a rotating disc with a pin pressed down on the surface.
The force, with which the pin is acting, can be adjusted by sliding a weight along the arm (Please see figure 1 (b)). In addition to the force, it is also possible to adjust the rotational speed of the disc.
The test rig is fitted with a force transducer that enables a calculation of the shaft torque, which in turn is used to determine the coefficient of friction.
Collection of data is carried out using Labview.

Test rig specifications:

Minimum contact pressure using a pin with a diameter of 5mm.:	3.97 $[MPa]$
Maximum contact pressure using a pin with a diameter of 5mm.:	84 $[MPa]$
Max. speed:	0.64 $[m/s]$

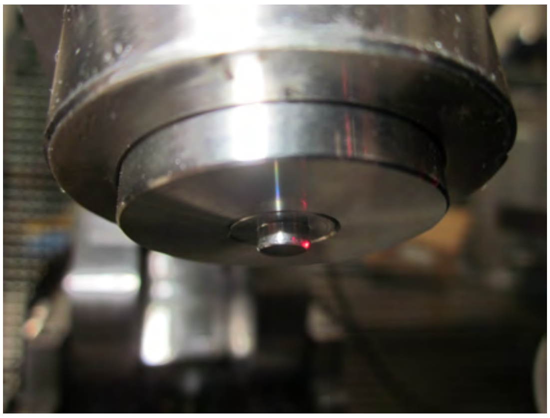


(a) Photo of test rig with the arm in elevated position.

(b) The steel block can be displaced along the arm, in order to change load.

(c) Photo of test disc

(d) Photo of test pin



(e) Photo of test pin mounted in adapter.

Figure 1: Photos showing "'Pin on Disc"'test rig.

3. Manufacturing of disc and pins.

3.1 Disc.

The disc used in these experiments is made from a piece of UIC 60 type rail. Please see figure 22 and 20 in appendix).

3.2 Pins

The pins are made from an IC3 wheel and an IC4 wheel.
On figure 2, we see how cylinders have been cut out from the wheel by means of a waterjet cutter.
These cylinders are subsequently manufatured into test pins (See drawing of pin on figure 21 in appendix).

The IC3 wheel is made from R8T steel, while the IC4 wheel is made from R7T steel (Pleace see table on figure 19 in appendix.).

(a)

(b)

Figure 2: Piece of train wheel.

4. Test results.

The data collected in the experiments will be presented in this section.

5 types of experiments have been conducted:

1. Preliminary dry test.
2. Test with grease.
3. Test with leaf sap (Deluted).
4. Test with water.
5. Test with leaf sap (Concentrated).

4.1 Preliminary test without lubrication.

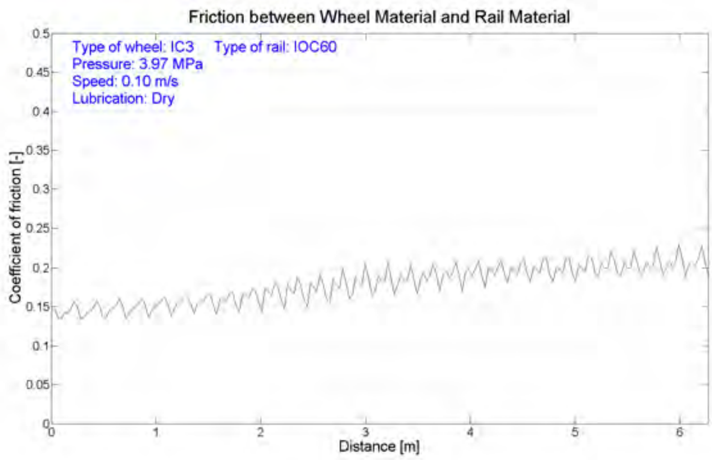
Pleace note that only pin's from the IC3 wheel have been used in these preliminary tests.
Figure 3(a) shows the plot for the first test. The pressure is 3.97MPa and no lubrication is used.
The graph shows that the coeffecient of friction did not have time to stabilize, so the distance should have been increased here.

On figure 3(b) the pressure is increased to 20.00MPa, and after approximately 6 m. there is a significant increase in friction. This increase is the result of the pin and disc being teared, as illustrated on figure 4(a) and 4(b).

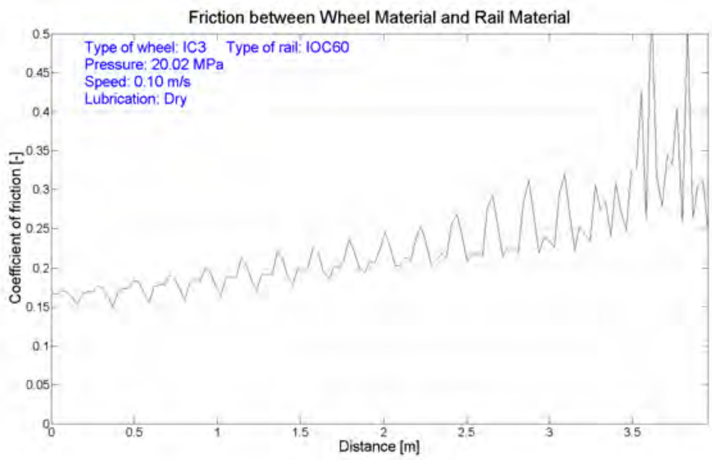
In an attempt to avoid tearing, a round was added to the pin. Figure 3(c) shows that tearing occurs after about 4 m., so adding a round has not corrected the problem with tearing.

The graph's on figure 3(a), 3(b) and 3(c) displays an oscillating pattern. One oscillation coincides with one revolution of the disc.
A possible explanation could be that the hardness is not the same everywhere on the disc, and that this variation in hardness might cause the coeffecient of friction to vary.

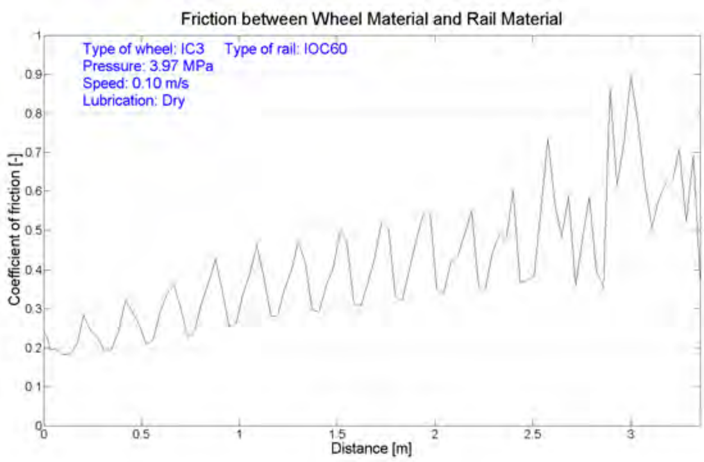
In order to be able to perform experiments with distances that allow for the coefficient of friction to stabilize, it was decided to perform the rest of the experiments with lubrication.



(a) First preliminary test.

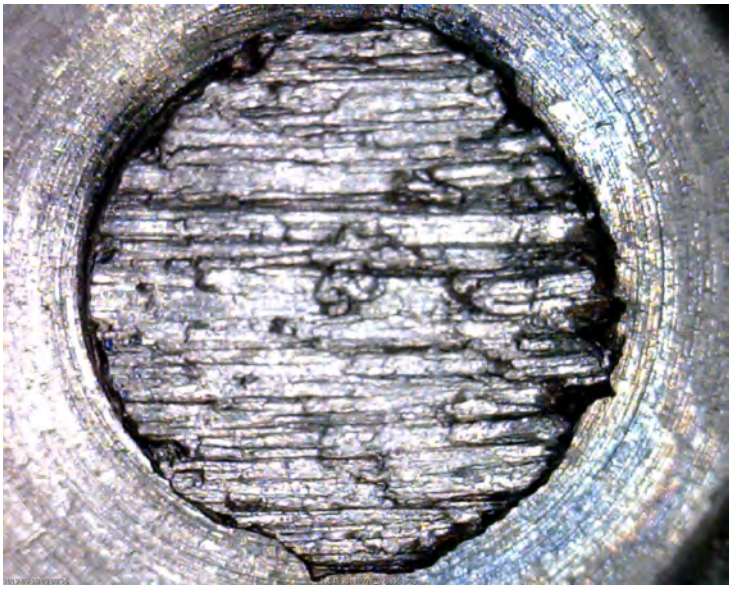


(b) Second preliminary test.

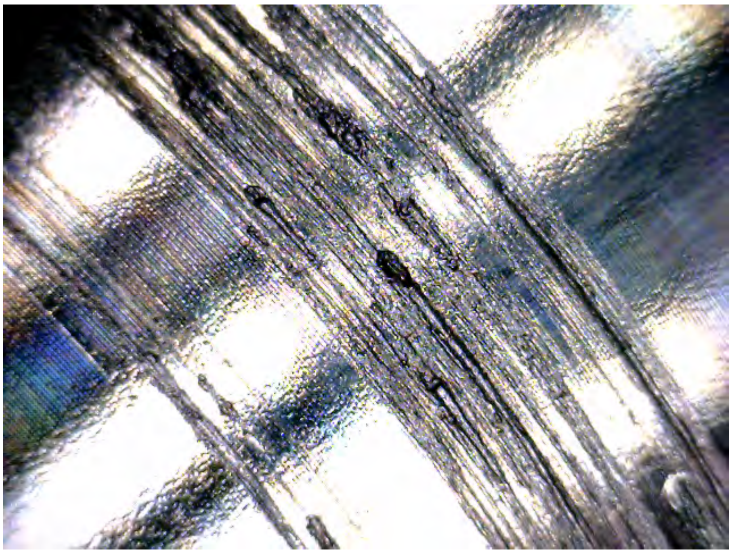


(c) third preliminary test. After a round has been added

Figure 3: Above we see the graphs for the tests where no lubrication was used. Notice that only IC3 pins were used in these preliminary tests.



(a) Pin after tearing.



(b) Disc after tearing.

Figure 4: Photos showing disc and pin after tearing.

4.2 Test with grease.

The experiments described in this section have been carried out using Rivolta F.L.G GT-2 as lubricant. (See datasheet in appendix)
To reduce the risc of tearing, the disk and pins were ground, in order to create a smoother surface.
The experiment was carried out by first applying a layer of grease to the disc, and then run the test (Please see figure 5).

On figure 6, 7 and 8 we see the test results for an IC3-pin and IC4-pin, at a contact pressure of 20MPa, 40MPa and 80MPa respectively.
In all three cases, the graphs show that the coeffecient of friction has stabilized within a distance of 3 m., and that there is no significant difference between the IC3- and IC4 test results.

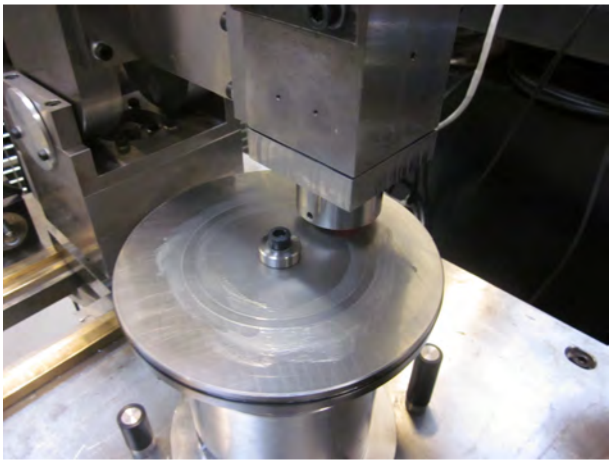
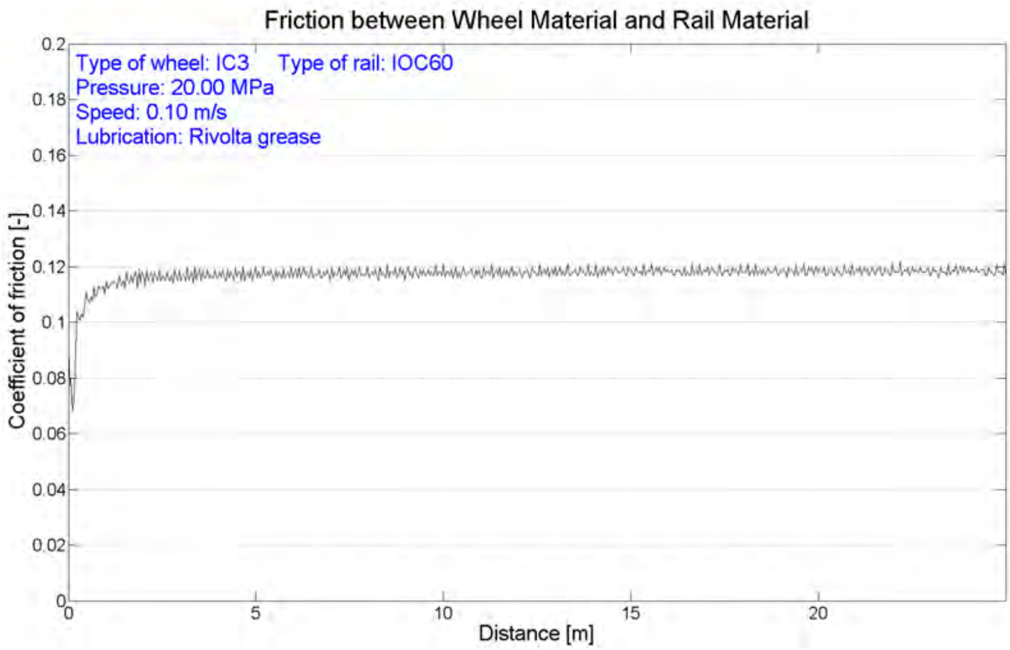
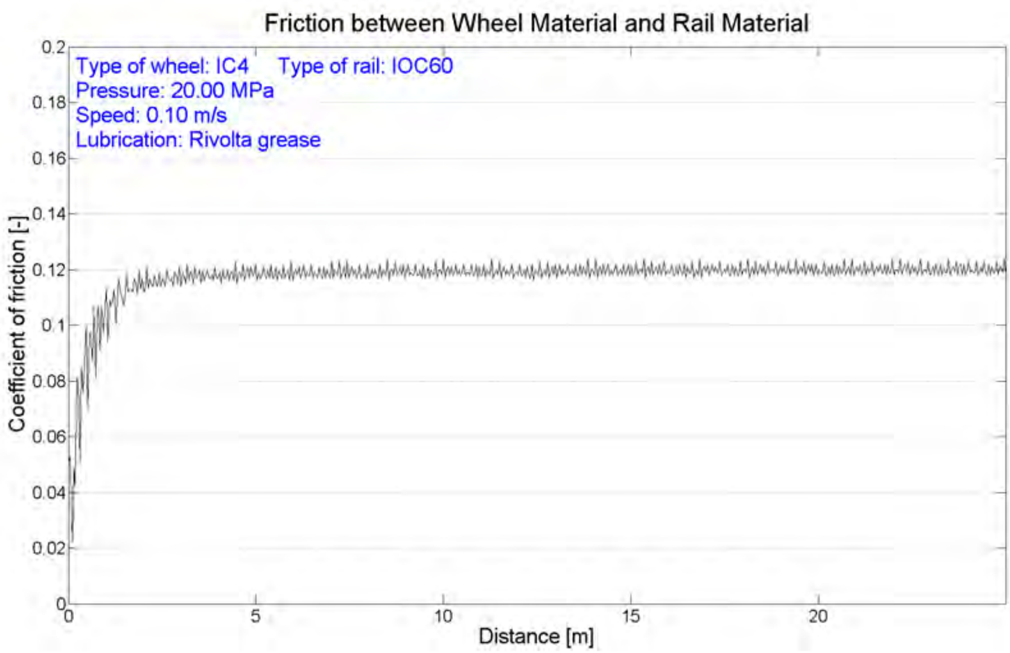


Figure 5: Experiments with Rivolta grease.

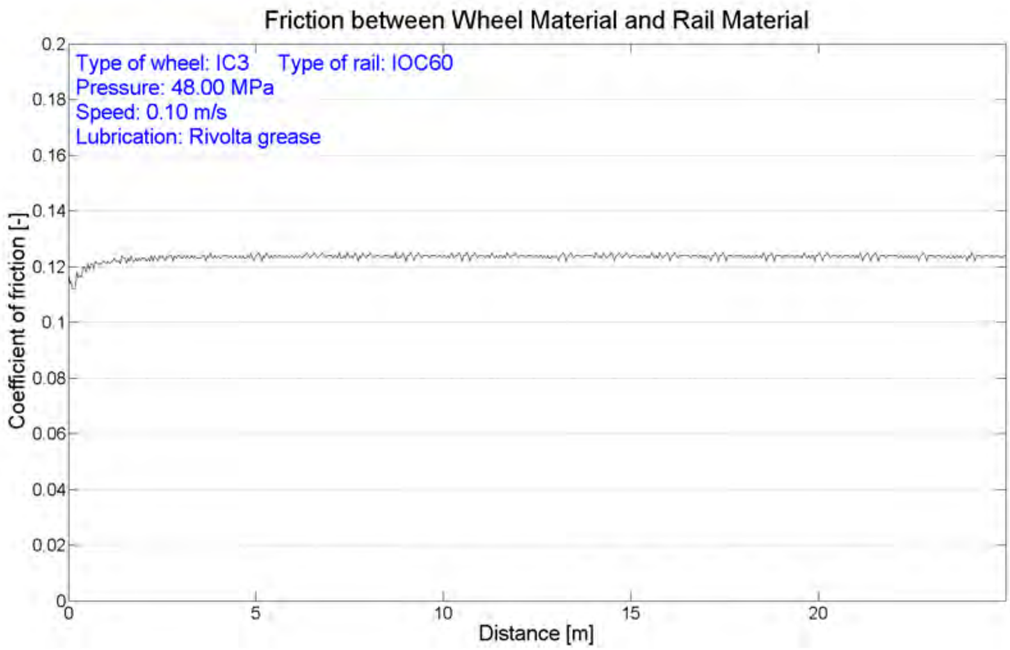


(a) Experiment with Rivolta grease and IC3-pin at 20MPa

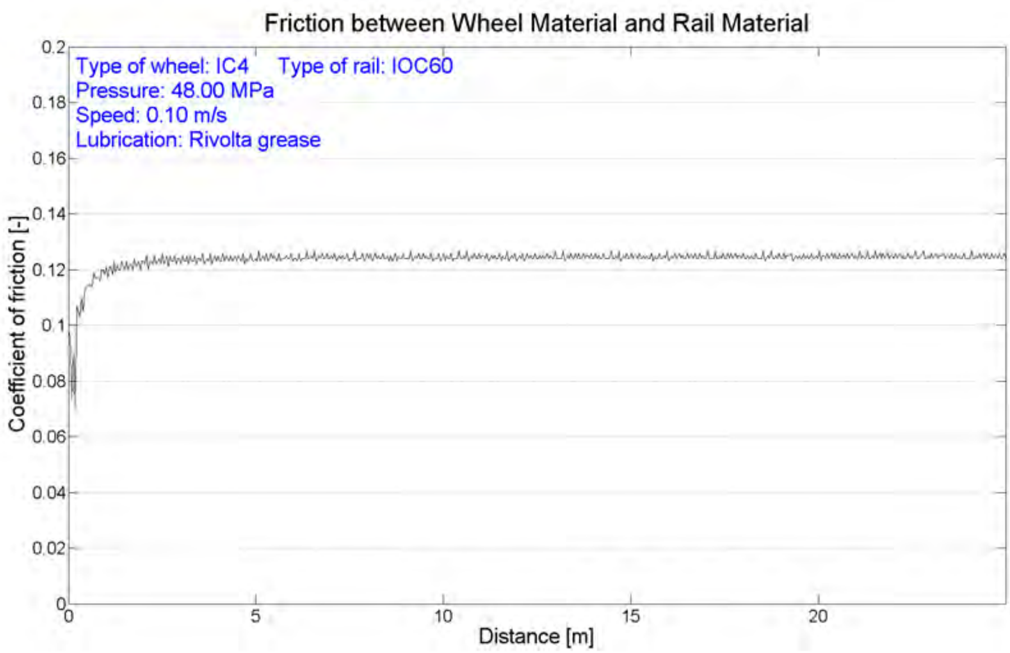


(b) Experiment with Rivolta grease and IC4-pin at 20MPa

Figure 6: Experiments with Rivolta grease at 20MPa

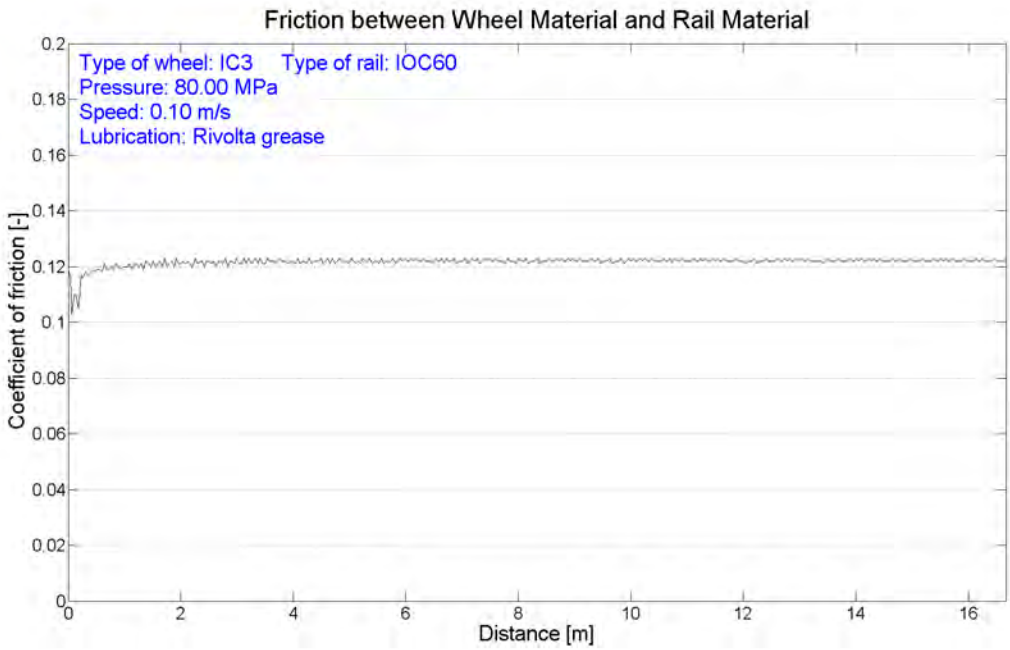


(a) Experiment with Rivolta grease and IC3-pin at 48MPa

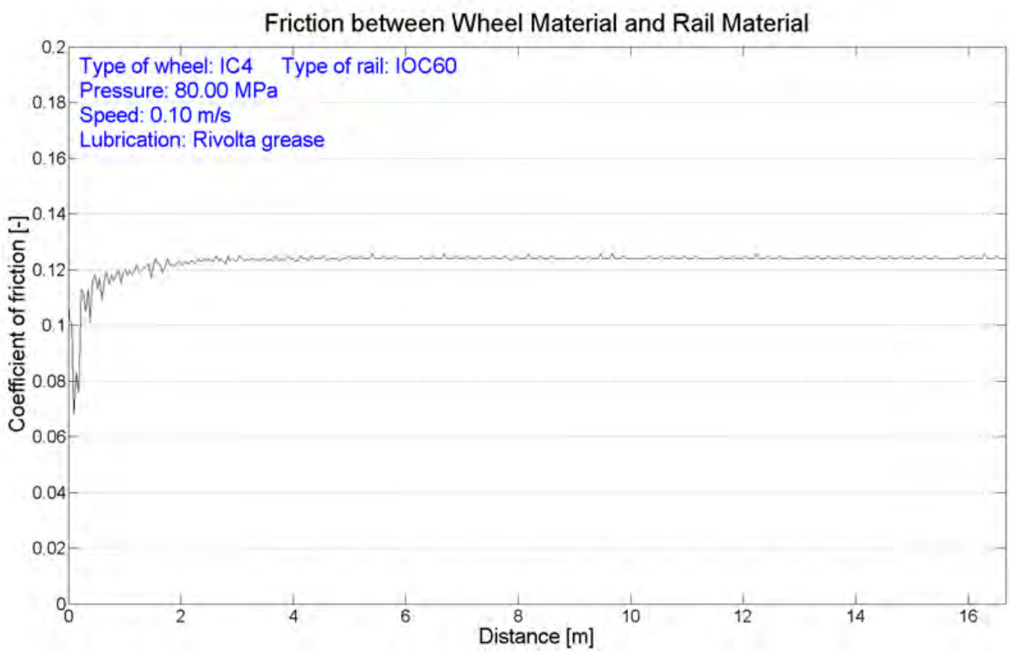


(b) Experiment with Rivolta grease and IC4-pin at 48MPa

Figure 7: Experiment with Rivolta grease at 48MPa



(a) Experiment with Rivolta grease and IC3-pin at 80MPa



(b) Experiment with Rivolta grease and IC4-pin at 80MPa

Figure 8: Experiment with Rivolta grease at 80MPa

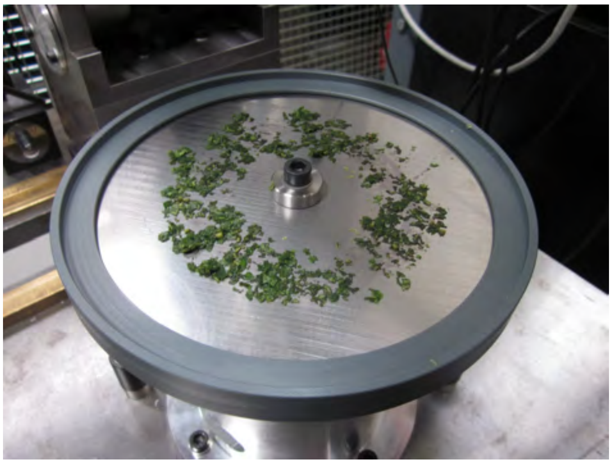
4.3 Test with leaf sap (Deluted)

For use in these tests, a small amount of beech leafs were collected. The leafs were finely chopped, and a small amount of water was added. Finally this mixture was placed on the disc (See figure 9).
The first experiment was stopped after a short while, as it became apparent that the chopped leafs were merely pushed away by the pin, without ever getting in between the pin and disc.

The next step was to squeeze the moisture out of the mixture and use this as a lubricant instead.
This fluid consisted mostly of water, but also a small amount of sap from the leafs. The test was carried out by applying a bit of the fluid to the pin track on the disc, and then begin the experiment.
The results of these experiments is shown in figure 10, 11 and 12.

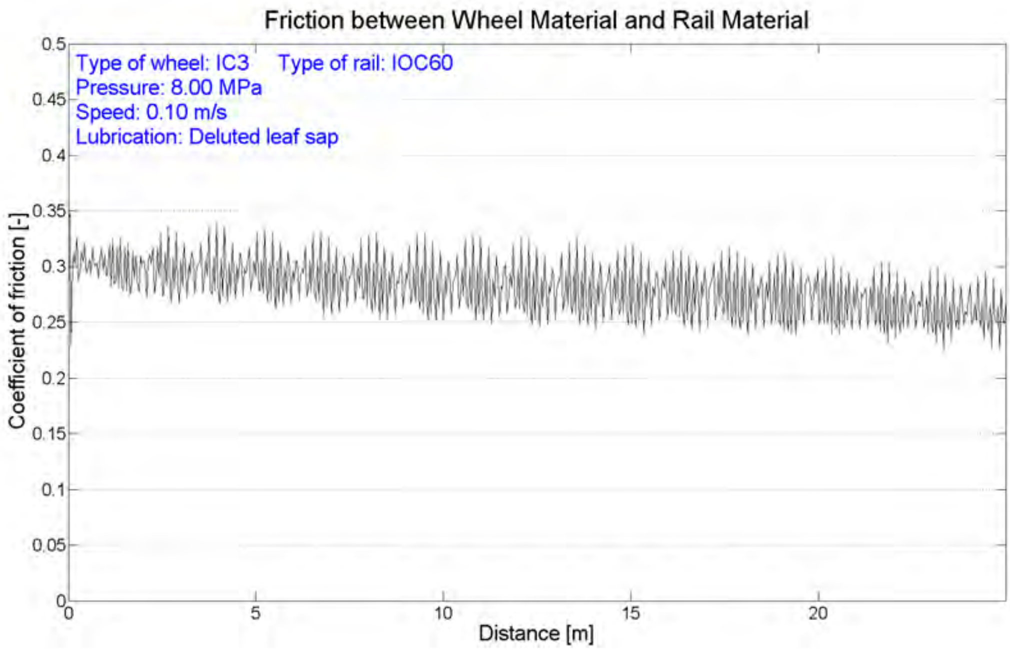
During these experiments, a slight decrease in the coeffecient of friction could be observed, as the water in the fluid evaporated. This can best be seen in figure 10(a) and 11(a).
The tendency towards a decrease in friction, as water evaporated, could suggest that the leaf sap had lubricating properties.

(a) Chopped beech leafs.

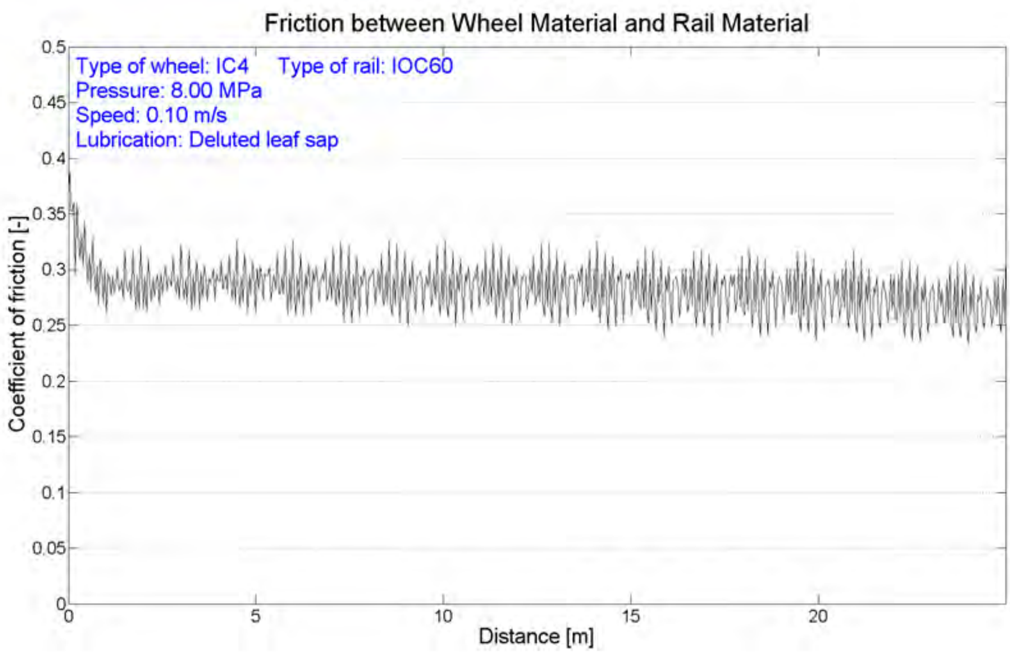


(b) Chopped beech leafs placed on disc.

Figure 9: Preparation of beech leafs.

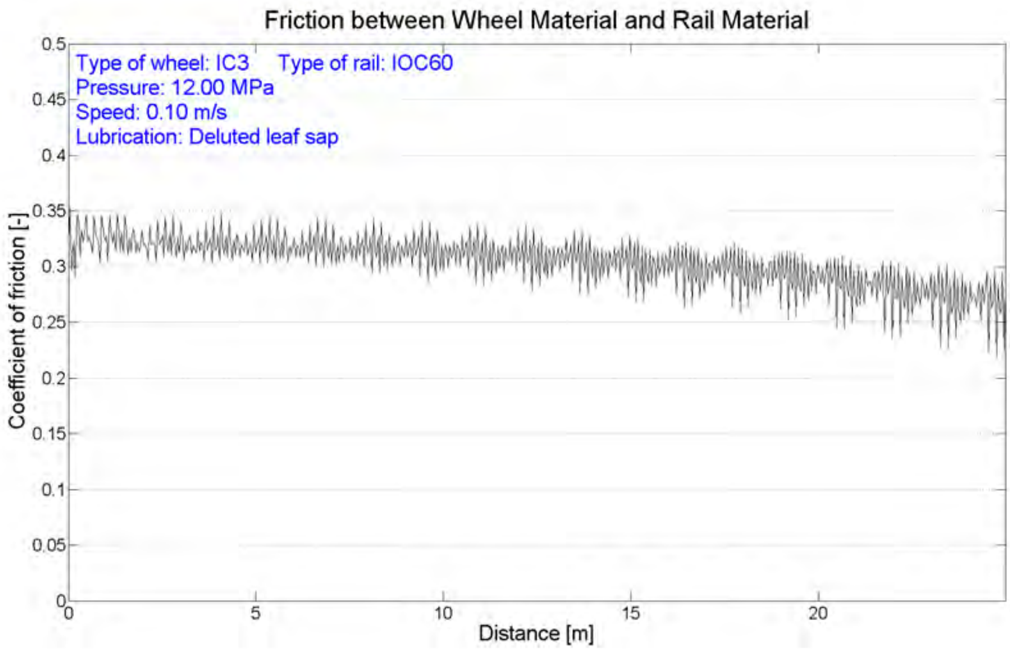


(a) Experiment with deluted leaf sap and IC3-pin at 8.0MPa.

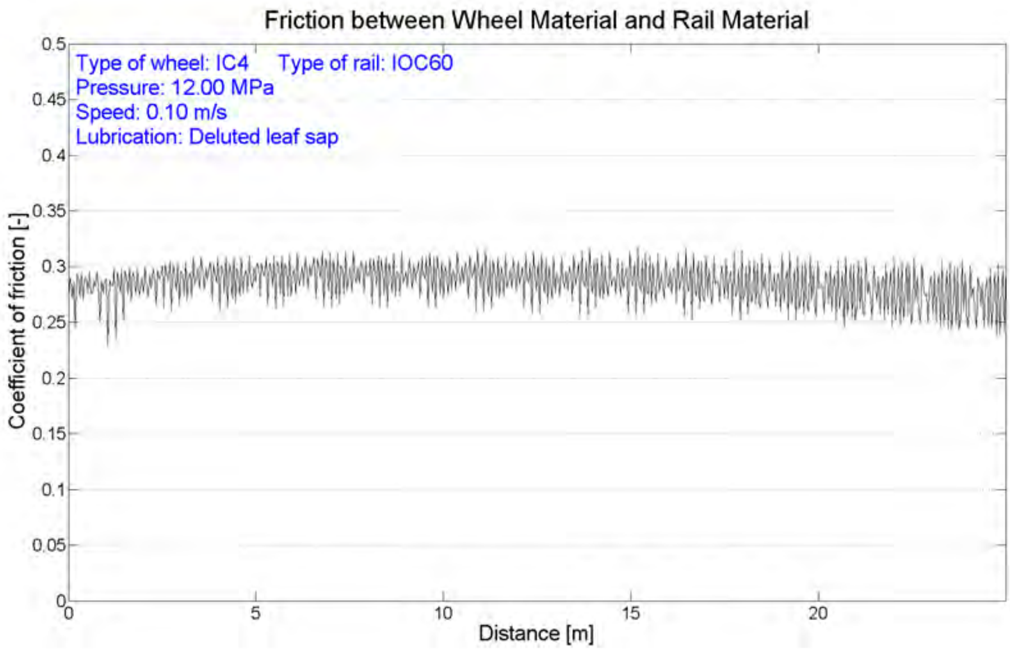


(b) Experiment with deluted leaf sap and IC4-pin at 8.0MPa.

Figure 10: Experiments with deluted leaf sap at 8.0MPa.

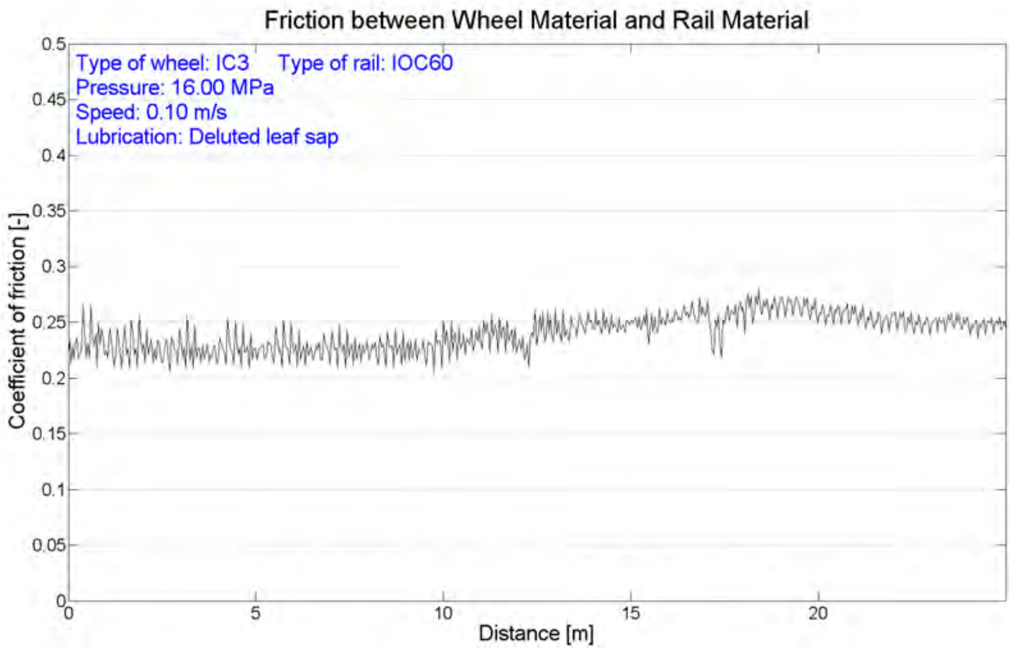


(a) Experiment with deluted leaf sap and IC3-pin at 12.0MPa.

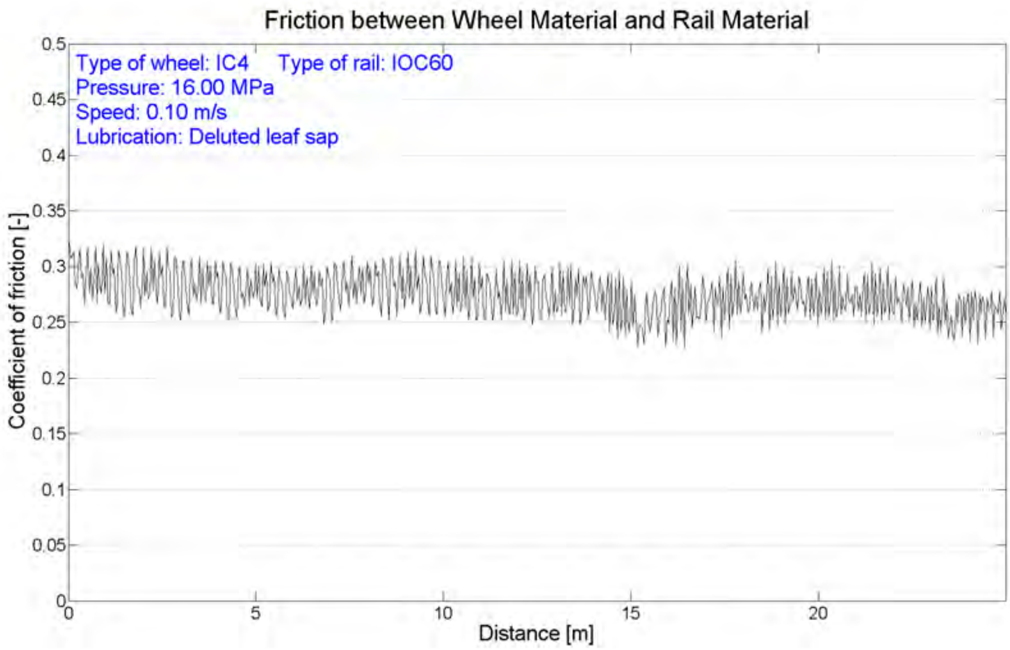


(b) Experiment with deluted leaf sap and IC4-pin at 12.0MPa.

Figure 11: Experiments with deluted leaf sap at 12.0MPa.



(a) [Experiment with deluted leaf sap and IC3-pin at 16.0MPa.



(b) [Experiment with deluted leaf sap and IC4-pin at 16.0MPa.

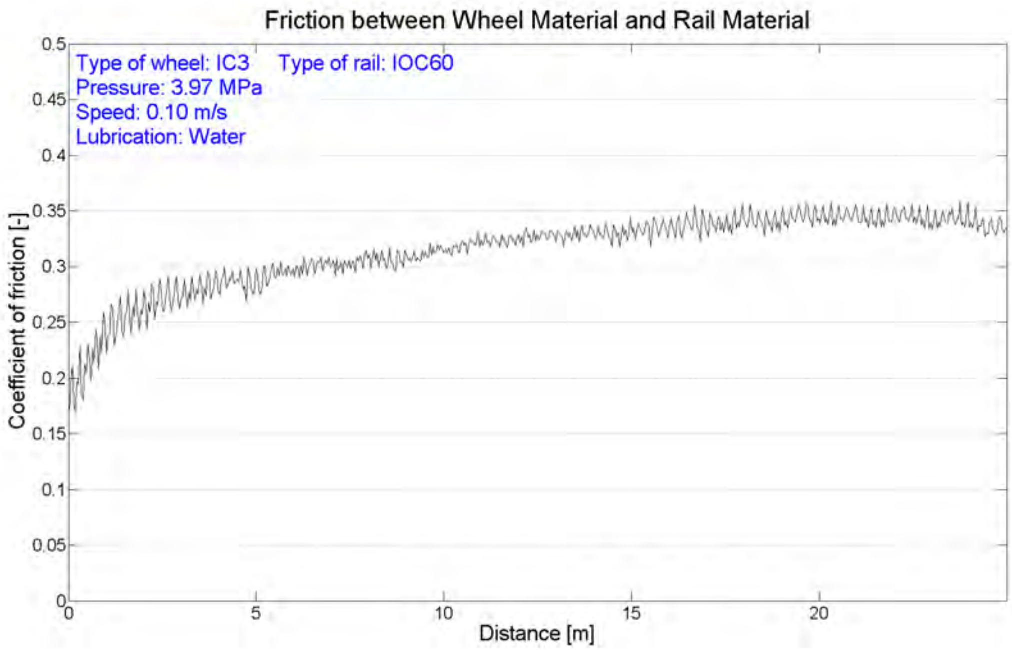
Figure 12: Experiments with deluted leaf sap at 16.0MPa.

4.4 Test with water.

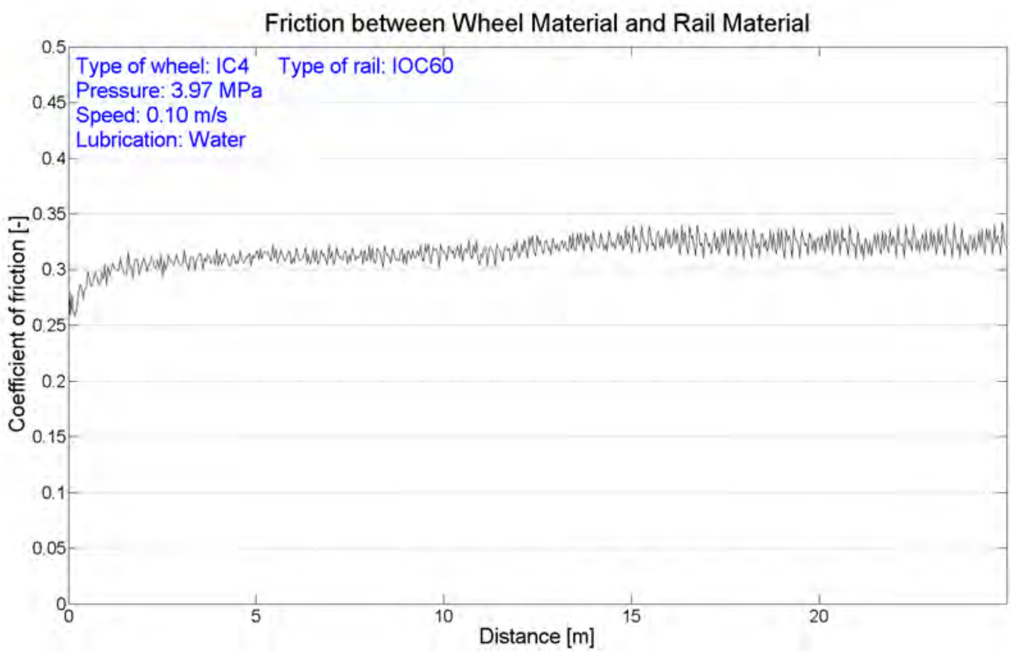
To find out wheter or not the leaf sap made any difference in the previous experiments, some experiments were performed using only water as lubricant.

On figure 13 and 14 wee see the plots of the experiments where water was used as lubricant.

A comparison of the graphs in figure 10 and 14, which both show the coefficient of friction at the same pressure and speed, shows that the coefficient of friction stabilizes at approximately 0.35 on figure 14(a) and (b), while it is between 0.25 and 0.30 on figure 10(a) and (b).
This could indicate that the deluted sap from the leafs is a better lubricant than water alone.

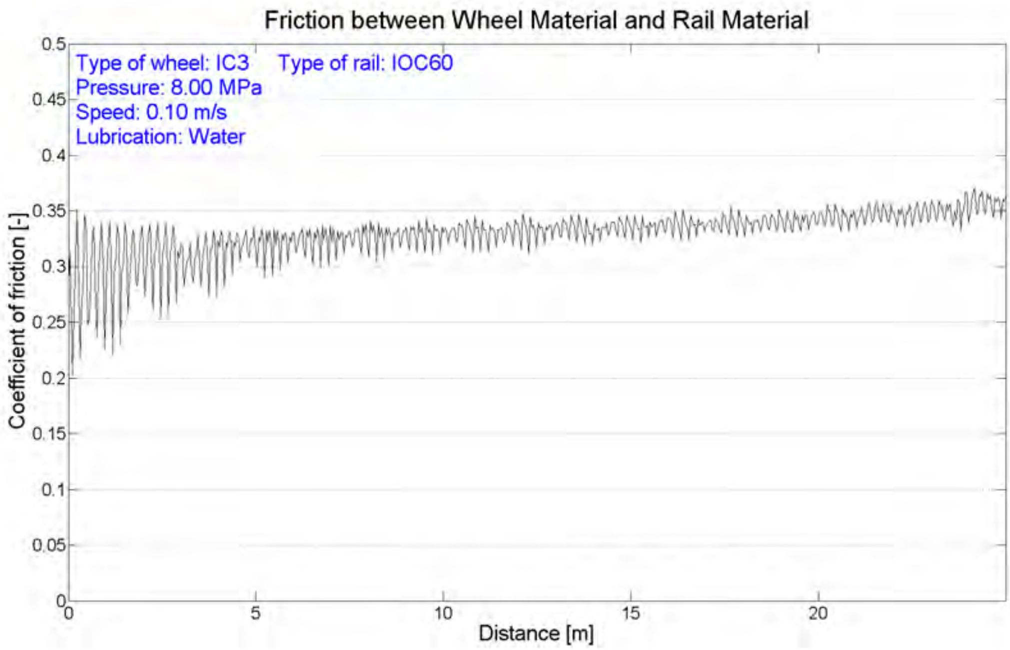


(a) Experiment with water and IC3-pin at 3.97MPa.

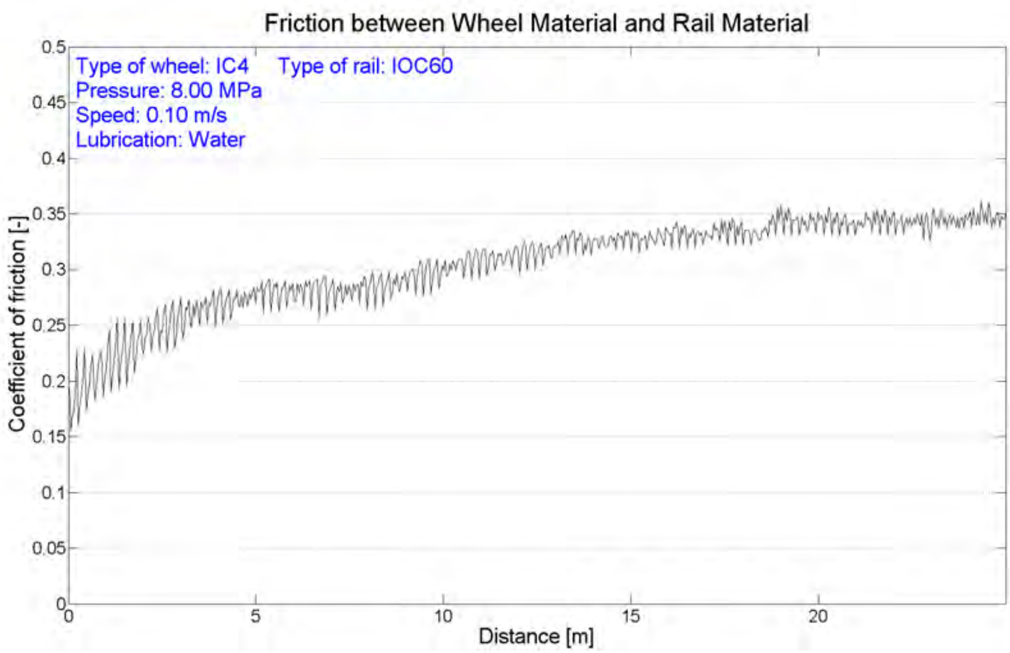


(b) Experiment with water and IC4-pin at 3.97MPa.

Figure 13: Experiments with water at 3.97MPa.



(a) Experiment with water and IC3-pin at 8.0MPa.



(b) Experiment with water and IC4-pin at 8.0MPa.

Figure 14: Experiments with water at 8.0MPa.

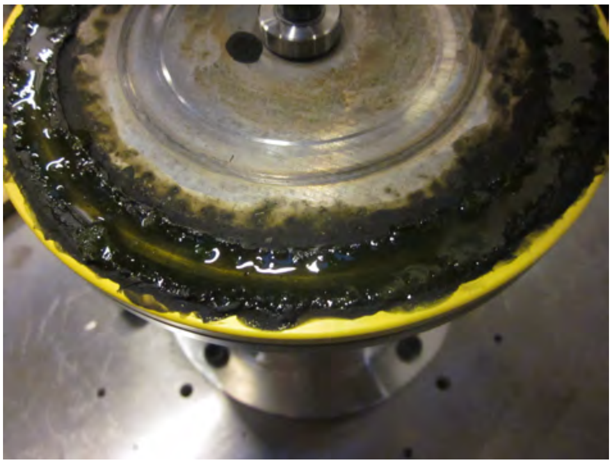
4.5 Test with leaf sap (Concentrated).

A series of experiments were conducted using a more concentrated leaf sap as lubricant.
The leaf sap was extracted by blending beech leafs into a pulp, and then squeezing the sap out.

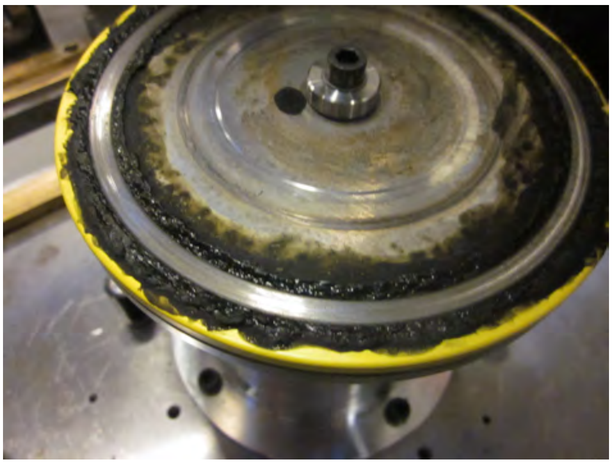
These experiments were carried out by first applying the lubricant to the pin trac (see figure 15(a)), and then run the test until the leaf sap had dried out (see figure 15(b)).

On figure 16, 17 og 18 wee see the test results from the experiments with concentrated leaf sap.
As was the case with the diluted leaf sap, there is a tendency towards lower friction as the water evaporates.
During the experiments, a significant decrease in friction could be observed just before the leaf sap dried out. Examples of this can be seen in figure 17(a) from approximately 160 to approximately 190 m. and in figure 17(b) from approximately 120 to approximately 140 m.

In figure 16 and 17, the IC3 pin and IC4 pin display similar behavior, but in figure 18 the coefficient of friction is significantly lower in the case of the IC3 pin than in the case of the IC4 pin. It should be noted that it is difficult to recreate the exact same test conditions in each test, when using this type of lubricant.

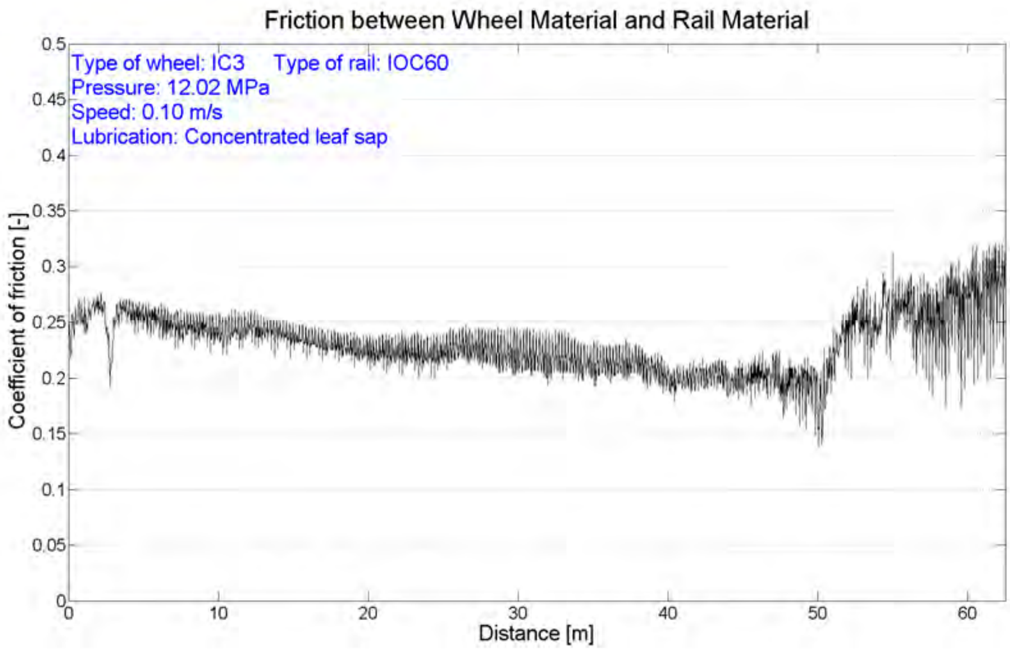


(a) The leaf sap is applied to the pin track.

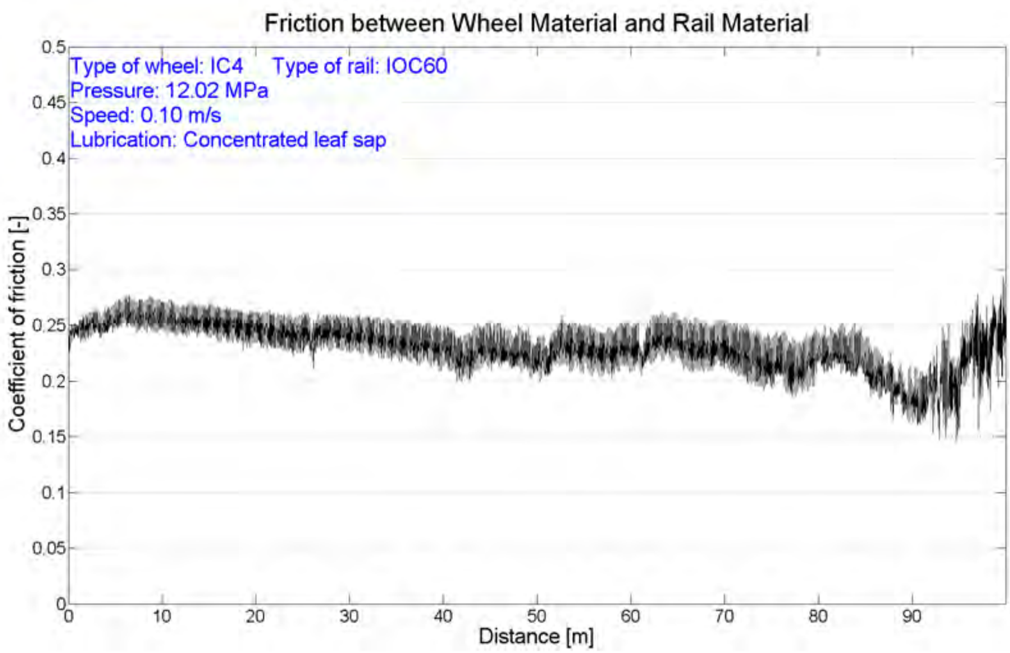


(b) Photo of dried out leaf sap.

Figure 15: Photos showing experiment with concentrated leaf sap.

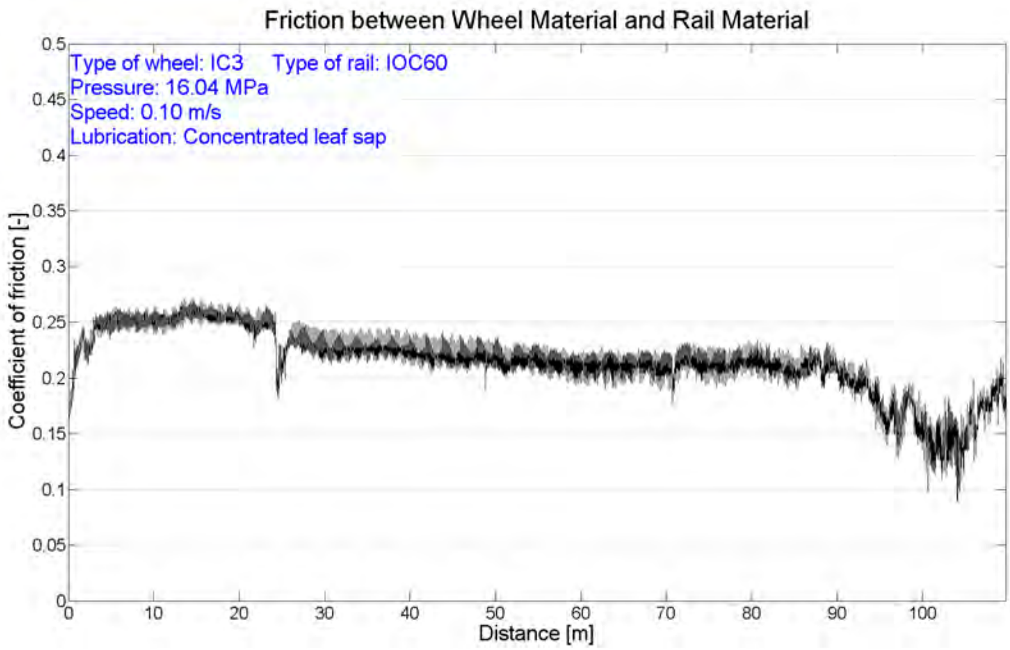


(a) Experiment with concentrated leaf sap and IC3-pin at 12.0 MPa

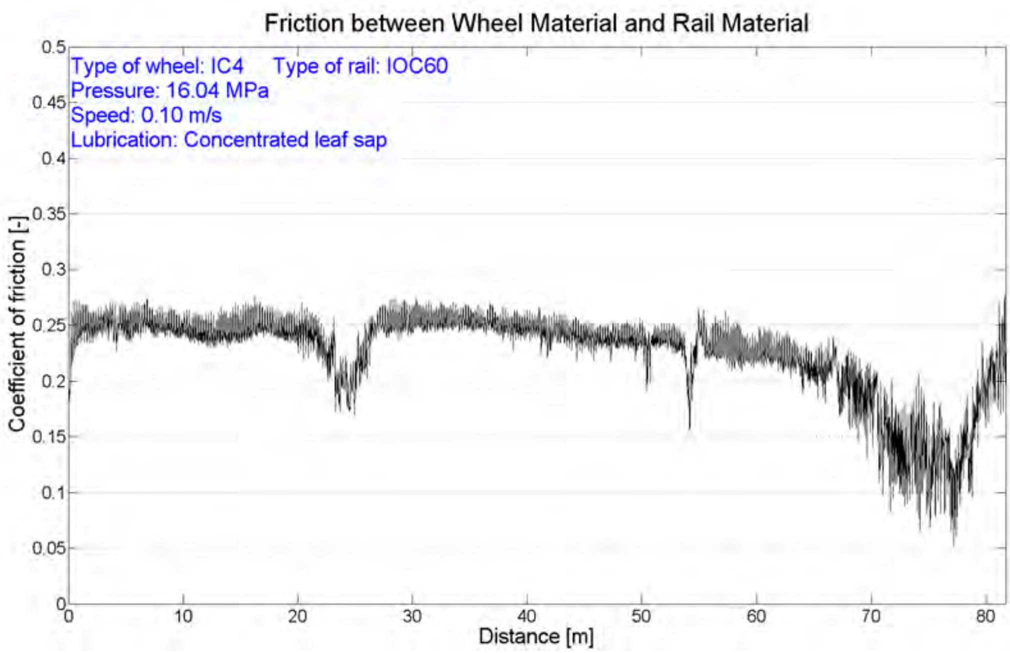


(b) Experiment with concentrated leaf sap and IC4-pin at 12.0 MPa

Figure 16: Experiments with concentrated leaf sap at 12.0 MPa

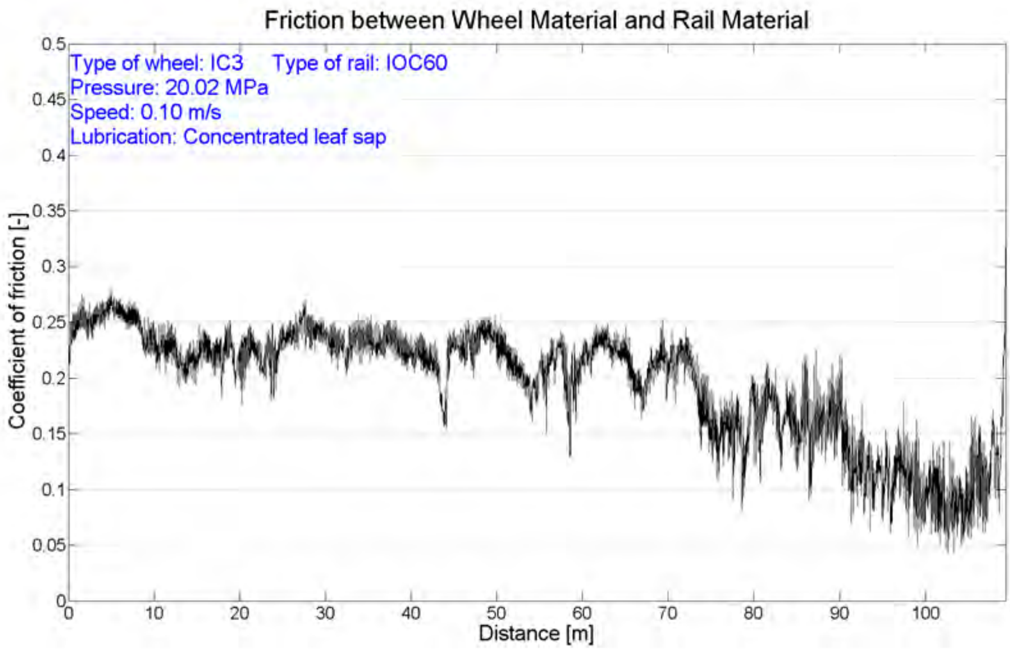


(a) Experiment with concentrated leaf sap and IC3-pin at 16.0 MPa

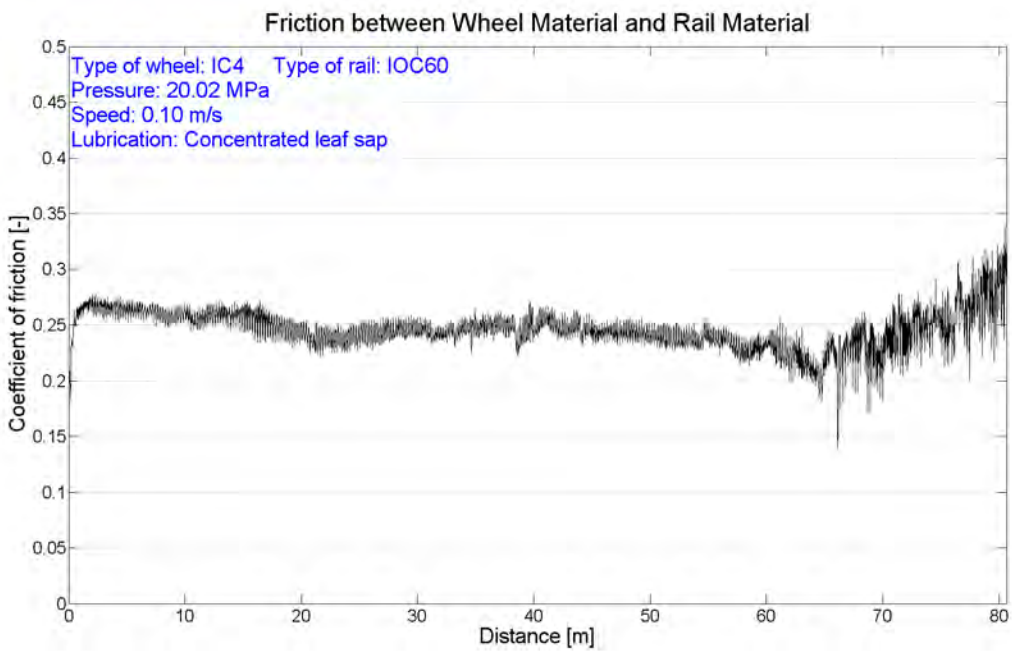


(b) Experiment with concentrated leaf sap and IC4-pin at 16.0 MPa

Figure 17: Experiments with concentrated leaf sap at 16.0 MPa



(a) Experiment with concentrated leaf sap and IC3-pin at 20.0 MPa



(b) Experiment with concentrated leaf sap and IC4-pin at 20.0 MPa

Figure 18: Experiments with concentrated leaf sap at 20.0 MPa

5. Conclusion.

A series of preliminary experiments have been conducted, in order to determine the coefficient of friction between a rail material and two different wheel materials. The experiments have been carried out at various loads, and using different types of lubrication.
These experiments allowed, to some degree, a comparison between the two wheel materials.

The experiments, where Rivolta grease was used as lubricant, do not show any significant difference between the two wheel types, in terms of the coefficient of friction.
Because grease is much more homogeneous and manegable than deluted and concentrated leaf sap, it was possible to perform each experiment under similar conditions.
So in this case it is reasonable to compare the results for the two types of wheel material.

The experiments with deluted leaf sap also show some agreement between the two wheel types, regarding the coefficient of friction, allthough not to the same degree as in the case with grease as lubricant.
It should be pointed out that using deluted leaf sap as lubricant makes it diffficult to create the same conditions from experiment to experiment, as the lubricant is not as homogenious and manegable as for example grease. So, in terms of the experiments performed with deluted leaf sap, a direct comparison of the results for the two wheel types would be problematic.

A comparison between the experiments with water and the experiments with deluted leaf sap indicated that the leaf sap had a lubricating effect.

To further study the presumed lubricating effect of leaf sap, a series of experiments were performed using a more concentrated leaf sap.
These experiments demonstrated that the leaf sap had a lubricating effect. They also showed a significant drop in friction, just as the leaf sap dried out, and subsequently an increase in friction after the leaf sap had dried out.
Some of the graphs, related to the experiments with concentrated leaf sap, display significant differences between the IC3- and IC4 results.
Again it should be noted that creating similar experimental conditions is difficult when using concentrated leaf sap as a lubricant. So a direct comparison of the two wheel materials, based on these results, is problematic.

The experiments, documented in this report, do not provide the basis to make definitive conclusions concerning possible differences between the IC3 wheel material and IC4 wheel material, with regard to friction characteristics. In order to do that, more experiments are required. In addition to this the method used in the experiments involving leaf sap, should be further developed in order ensure similar conditions in each experiment.

In conclusion, the experiments documented in this report have demonstrated that leaf sap can have lubricating properties. Furthermore, the experiments with Rivolta grease, where it was possible to create similar experimental conditions, did not show a significant difference between the IC3- and IC4 results.

6. Appendix.

6.1 Wheel material.

Appendix I – Wheel Chemistry Table

WHEEL STEEL CHEMICAL ANALYSIS LEVELS

STANDARD	COUNTRY OF ORIGIN	GRADE	CARBON % (MAX)	SILICON % (MAX)	MANG. % (MAX)	PHOS. % (MAX)	SULP. % (MAX)	CHROME % (MAX)	COPPER % (MAX)	MOLYB. % (MAX)	NICKEL % (MAX)	VAN. % (MAX)	CR+MO+NI % (MAX)	HYDROGEN PPM (MAX) CAT1	CAT2
JIS E5402	JAPAN	C44	0.46	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
AAR M107*	N.AMERICA	L	0.47	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
BS5892:PT3	UK	R6T	0.48	0.40	0.75	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER6	0.48	0.40	0.75	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
JIS E5402	JAPAN	C48	0.50	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
GOST 10791	RUSSIA	GRADE 1	0.44/0.52	0.40/0.65	0.80/1.20	0.035	0.030	0.30	0.30	0.08	0.30	0.08/0.15	N/S	2.0	2.0
BS5892:PT3	UK	R7T	0.52	0.40	0.80	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER7	0.52	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
IRSS	INDIA	R19	0.52	0.15/0.40	0.60/0.80	0.030	0.030	0.25	0.28	0.06	0.25	0.05	0.50	3.0	3.0
JIS E5402	JAPAN	C51	0.54	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
VALDUNES	FRANCE	R8TUCS	0.54	0.30/1.10	0.60/1.10	0.020	0.005/0.020	0.30/0.50	0.30	0.08	0.30	0.06	0.65	2.0	2.5
FSR	FINLAND	ER8MOD	0.52/0.56	0.90/1.10	0.90/1.10	0.015	0.006	0.30	0.10	0.08	0.30	0.08	0.05	2.0	2.0
LUCCHINI	ITALY	SUPERLOS	0.49/0.56	0.60/1.10	0.60/1.10	0.015	0.020	0.30	0.30	0.08	0.30	0.08	0.05	1.8	1.8
BS5892:PT3	**UK**	**R8T**	**0.56**	**0.40**	**0.80**	**0.040**	**0.040**	**0.30**	**0.30**	**0.08**	**0.30**	**0.05**	**0.60**	**2.0#**	**2.0#**
EN13262	EUROPE	ER8	0.56	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
AAR M107*	N.AMERICA	A	0.47/0.57	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
JIS E5402	JAPAN	C55	0.58	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
BS5892:PT3	UK	R9T	0.60	0.40	0.80	0.040	0.040	0.30	0.30	0.08	0.30	0.05	0.60	2.0#	2.0#
EN13262	EUROPE	ER9	0.60	0.40	0.80	0.020	0.015	0.30	0.30	0.08	0.30	0.06	0.50	2.0	2.5
GOST 10791	RUSSIA	GRADE 2	0.55/0.65	0.22/0.45	0.50/0.90	0.035	0.030	0.30	0.30	0.08	0.30	0.10	N/S	2.0	2.0
TB/T 2708	CHINA	CL60	0.55/0.65	0.17/0.37	0.50/0.80	0.040	0.040	0.25	0.25	N/S	0.25	N/S	0.50	N/S	N/S
GOST 10791	RUSSIA	GRADE 3	0.58/0.67	0.22/0.45	0.50/0.90	0.035	0.030	0.30	0.30	0.08	0.30	0.08/0.15	N/S	2.0	2.0
JIS E5402	JAPAN	C64	0.67	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S
AAR M107*	N.AMERICA	B	0.57/0.67	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
IRSS	INDIA	R34	0.57/0.67	0.15 MIN	0.60/0.90	0.030	0.030	0.25	0.28	0.06	0.25	0.05	0.50	2.5	2.5
AAR M107*	N.AMERICA	C	0.67/0.77	0.15/1.00	0.60/0.90	0.030	0.005/0.040	0.25	0.35	0.10	0.25	0.04	N/S	N/S	N/S
JIS E5402	JAPAN	C74	0.77	0.40	0.90	0.040	0.040	0.30	0.30	0.08	0.30	0.05	N/S	N/S	N/S

LIMITS SPECIFIED ARE MAXIMUM UNLESS SPECIFIED OTHERWISE

2PPM LEVEL AS REQUIRED BY RAILWAY GROUP STANDARD GM/RT2466

* AAR SPECIFICATION ALSO HAS AL 0.060 MAX, TITANIUM 0.03 MAX AND NIOBIUM 0.05 MAX.

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Figure 19: Table of wheel materials.

6.2 Rail profile.

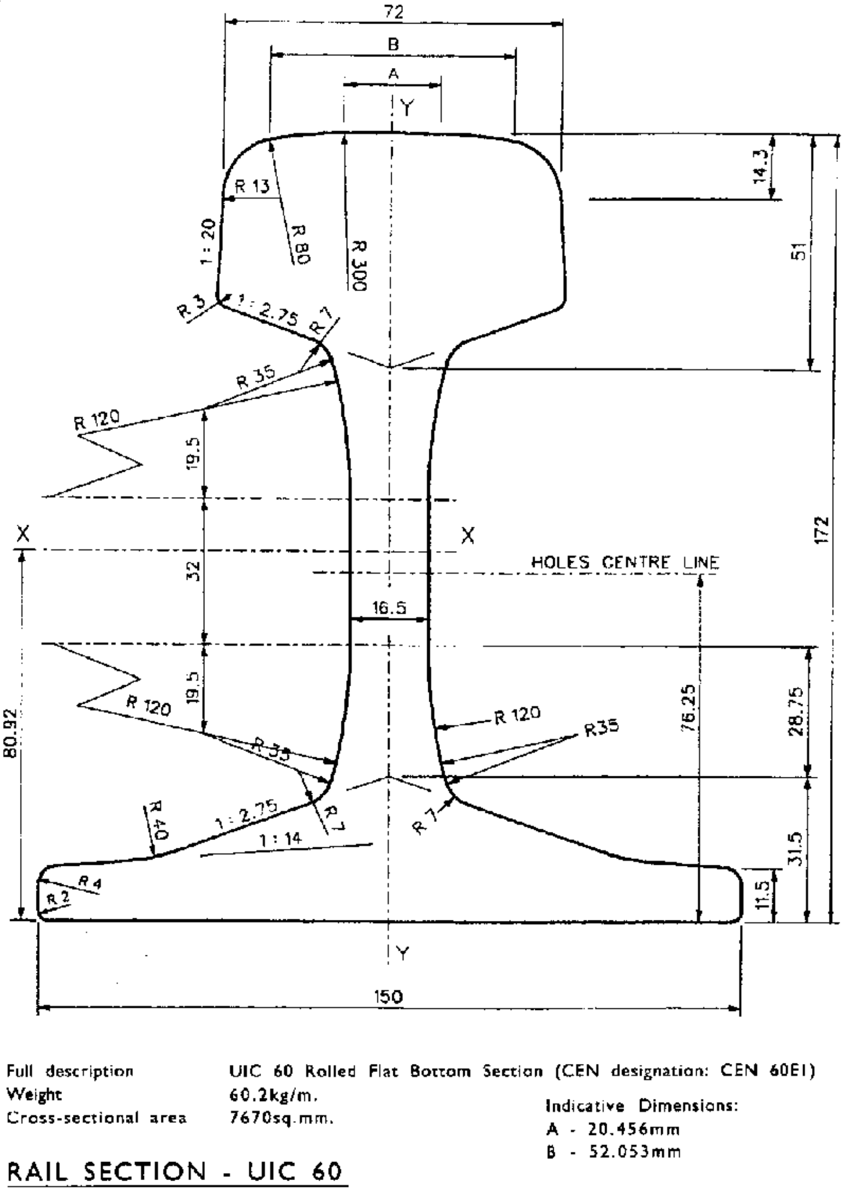


Figure 20: Drawing of UIC60 rail profile.

6.3 Working drawing of pin.

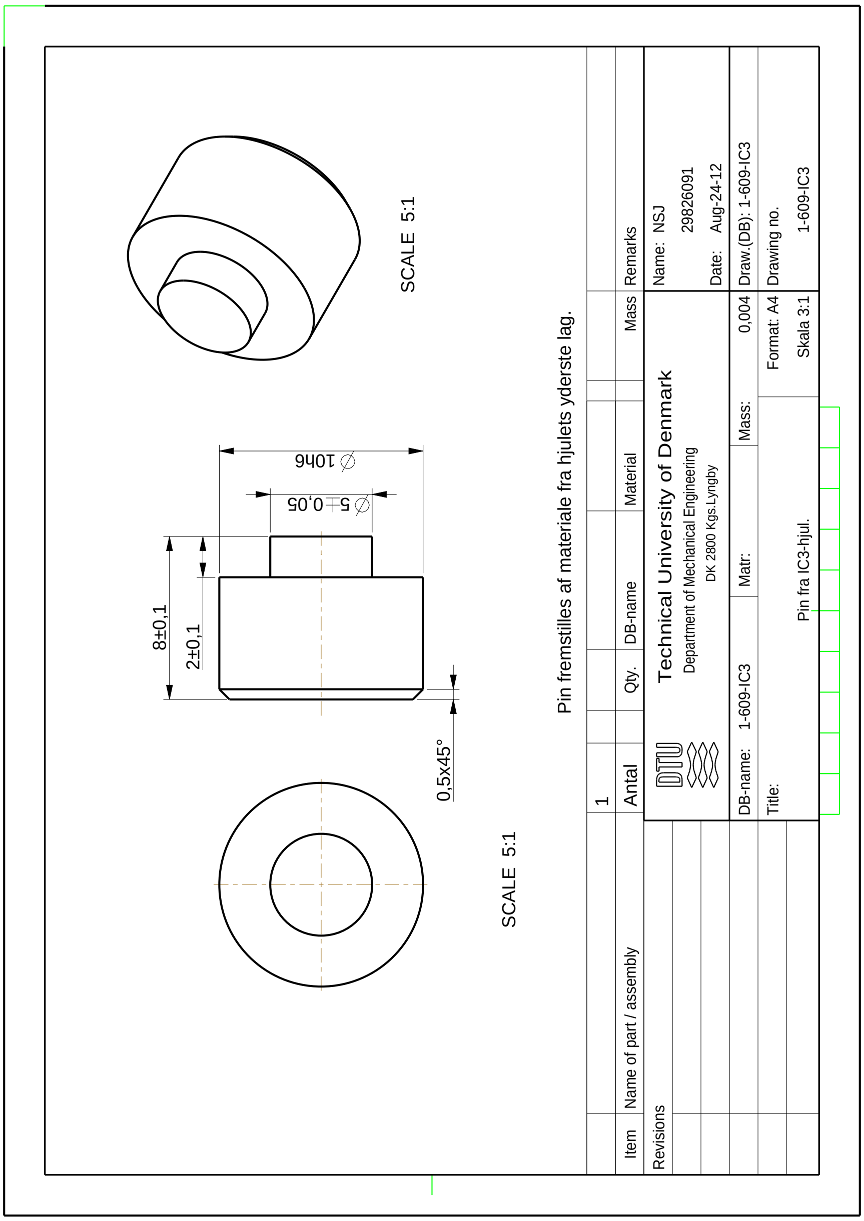


Figure 21: Working drawing of pin.

6.4 Working drawing of disc.

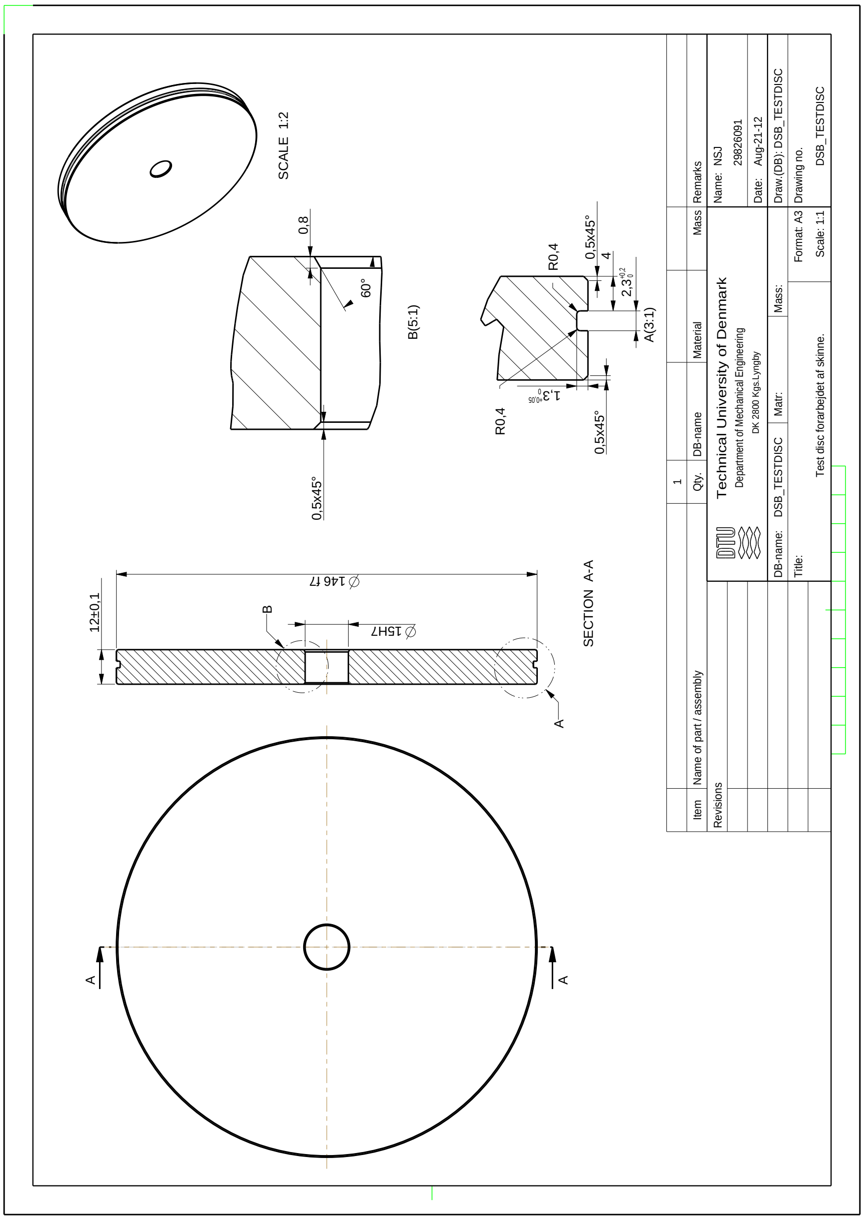


Figure 22: Working drawing of disc.

6.5 Data sheet for Rivolta F.L.G GT-2.

Rivolta® FLG GT-2

Universalfett för höga och låga temperaturer inom livsmedelsindustrin

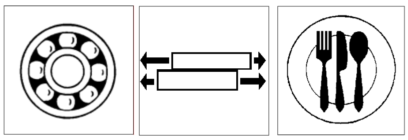
Produktbeskrivning

Rivolta FLG GT-2 är ett helsyntetiskt smörjfett utvecklat för livsmedels– och läkemedelsindustrin. Rivolta FLG GT-2 är ett mekaniskt stabilt, extremt vattenresistent, termiskt stabilt smörjfett utvecklat för smörjning av högt belastade rullnings– och glidlager samt i glidytor inom temperaturområdet –45°C till +170°C. Tack vare sin låga dynamiska friktion kan produkten användas både i snabbroterande lager och i låga temperaturer. Produkten är biologiskt inert och tillverkad enligt bestämmelser från US FDA där tillfällig kontakt med livsmedelsprodukter kan inträffa.

- **Temperaturområde: -45 till +170°C**
- **Hög termisk stabilitet.**
- **Vattenresistent.**
- **Oxiderings- och åldringsbeständig.**
- **Enkel att pumpa.**
- **Minimal friktion och slitage.**
- **Registrerat enligt NSF H1, Kosher och Canadian Food Inspection Agency.**

Användningsområden

- Rullningslager - högt belastade spårkullager, koniska rullnings– och nållager vid extremt låga och höga temperaturer som t.ex. lager i frystunnlar, bakautomater och torkugnar, lager i elektriska motorer, ventilatorer, varmluftsventilatorer, lager i ugnar och conveyrar och torkar.
- Glidlager exponerade för höga temperaturer.
- För lager och glidytor i låga temperaturer.
- För snabbroterande glid– och rullningslager av alla typer.
- För smörjning av skruvar, bultar, leder, kamkurvor och andra rörliga delar.



Rullningslager Glidlager NSF H1

Kompatabilitet

RIVOLTA FLG GT-2 är inte aggressiv mot metaller, plaster, lacker eller mineraloljeresistenta tätningsmaterial. Blanda ej med andra typer av smörjfett.

Applicering

Rengör smörjpunkterna så noga som möjligt från gamla rester och föroreningar.

Registrerad NSF (H1) Kosher och Canadian Food Inspection Agency. Produkten är godkänd av United States Food and Drug Administration (FDA). Föreskrifterna är fastslagna i CFR 21, sektion 178.3570 (smörjfetter med tillfällig kontakt med livsmedel). Produkten innehåller inga naturliga substanser från djur eller genetiskt modifierade organismer. Produkten är biostatisk, gynnar inte mikrobiell- eller mögelväxt.

Postadress	E-post	Web	Telefon	Telefax	Bank	Postgiro
Varlabergsvägen 6 434 39 Kungsbacka	info@gleitmo.se	www.gleitmo.se	0300 333 33	0300 143 00 VAT no SE556192115501	Handelsbanken Bankgiro 442-8959	8 46 35-2

Tekniska Data

	Värde	Enhet	Testmetod
Färg	ljus	-	-
Densitet	0,945	g/ml	DIN 51757
Basoljeviskositet @+40°C	46	mm²/s	DIN 51562-1
NLGI-grad	2	-	DIN 51818
Bearbetad penetration	265-295	1/10mm	DIN/ISO 2137
Minskning av penetrationstal efter 100.000 dubbelslag	<30	1/10mm	-
Temperaturområde*1	-45/+170	°C	-
Droppunkt	>250	°C	DIN/ISO 2176
Korrosionsskydd på stål	0/0	Korr.grad	DIN 51802
Korrosionsskydd på koppar	1	Korr.grad	DIN 51811
Basoljeseparation 18tim @ +40°C	<0,5	%	DIN 51817
Vattenresistens 3 tim @ +90°C	0	-	DIN 51807-1
SRV-test*2 **Friktionskoefficient min** **Friktionskoefficient max** **Slitage kula** **Slitage platta**	 0,08 0,09 0,45 <1,0	 - - mm µm	DIN 51834

*1—Kortfristigt upp till +200°C
*2—T=+190°C, F=200N

Riskupplysning

Undvik långvarig och ofta upprepad hudkontakt. För närmare information - se separat varuinformationsblad.

091223/SB

Postadress	E-post	Web	Telefon	Telefax	Bank	Postgiro
Varlabergsvägen 6 434 39 Kungsbacka	info@gleitmo.se	www.gleitmo.se	0300 333 33	0300 143 00 VAT no SE556192115501	Handelsbanken Bankgiro 442-8959	8 46 35-2

Technical University of Denmark

Initial Rheology Study on Concentrated Sugar Solutions

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Danish Polymer Center
Spring 2013, Kgs. Lyngby

Contents

1 Introduction

In the investigation into the incidences of the IC4's breaking failure, it was proposed that the failure originated from leaves present on the train tracks. It was observed that at under certain conditions where these leaves present on the train tracks reached a certain critical water content the friction decreased by orders of magnitudes. To further understand this mechanism the rheological properties of leaves with varying water contents is worth investigating. As an initial approximation the rheology of very concentrated sugar solutions is investigated. In this case, skim milk powder is dissolved in water yielding solutions primarily containing lactose and water.

2 Experimental

Preparation of the sample was performed by dissolving milk powder in enough water that a homogeneous solution was obtained. Subsequently, as much water as possible was removed from the sample on a rotary evaporator. The viscosity was measured on an ARES sheer rheometer with a 60mm aluminum plate-plate geometry. To avoid evaporation from the sample during measurements a solvent trap was constructed on the bottom plate as follows (see Figure 1). The sample was placed in the ARES and the top plate was lowered and brought in contact with the sample according to standard procedures. A roll of silly pudding was placed close to the outer rim of the lower plate creating a wall surrounding the sample. Mineral oil with a viscosity considerably lower than the viscosity of the sample was placed in the vacancy between the wall and the sample.

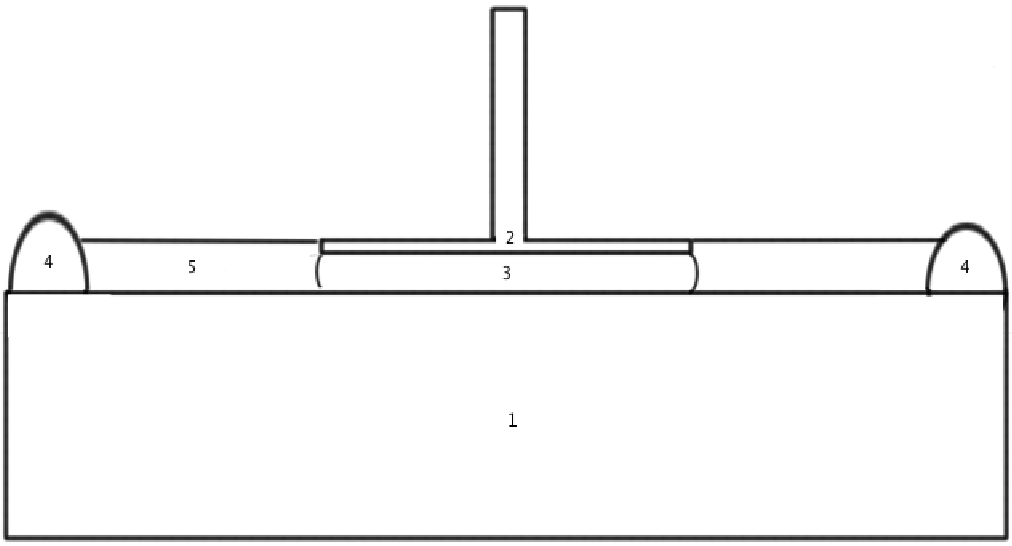

Fig. 1: Cross sectional view of the experimental setup: 1) Bottom plate, 2) Top plate, 3) Sample, 4) Silly pudding wall, 5) Mineral oil.

A strain sweep was performed in order to determine the linear region of the sample. Subsequently oscillation frequency and time sweeps were performed for the strain found in the linear region. The measurements were performed at 25^oC on samples with the concentrations displayed in Table 1.

Tab. 1: Sample specifications

Sample No.	Powder Conc. $[w\%]$
1	70.9
2	71.5
3	68.8

3 Results

In figure 2 two oscillation frequency sweeps are displayed for sample no. 1. The second run was made in hopes of reproducing the results from the first run.

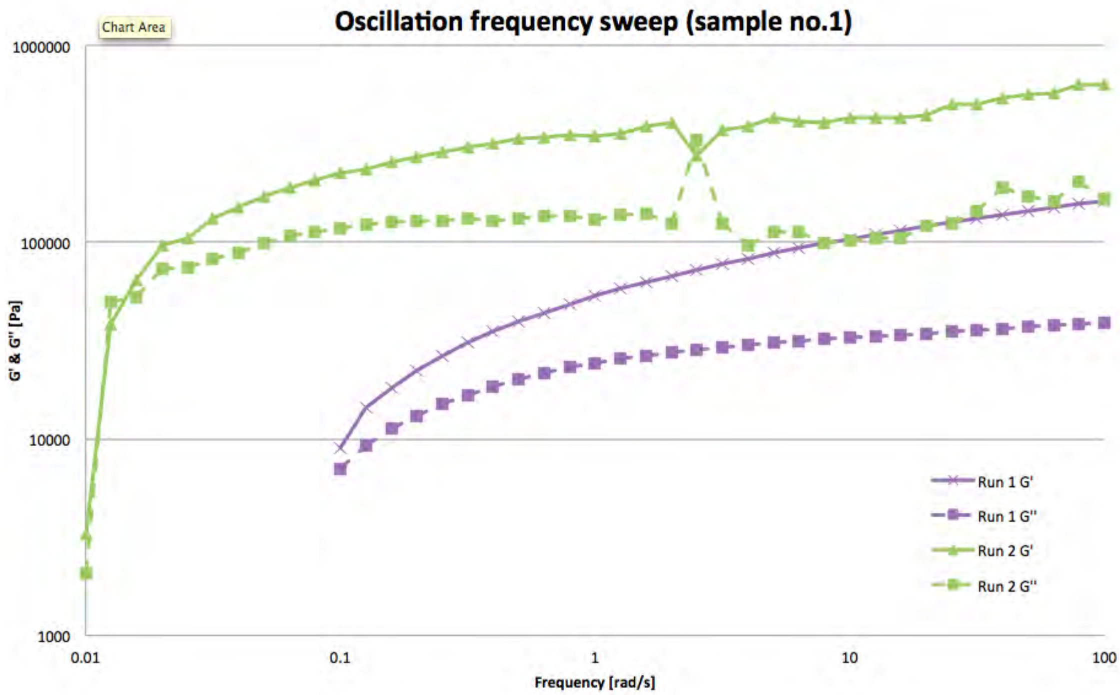

Fig. 2: Oscillation frequency sweep at 0.07 % strain with repetition.

In figure 2 it is seen that the viscosity is larger for the second run. Further more the results for the second run seem to be less smooth which could be a sign of crystallization. Figure 3 display the first oscillation frequency sweeps for sample no 1 and 2.

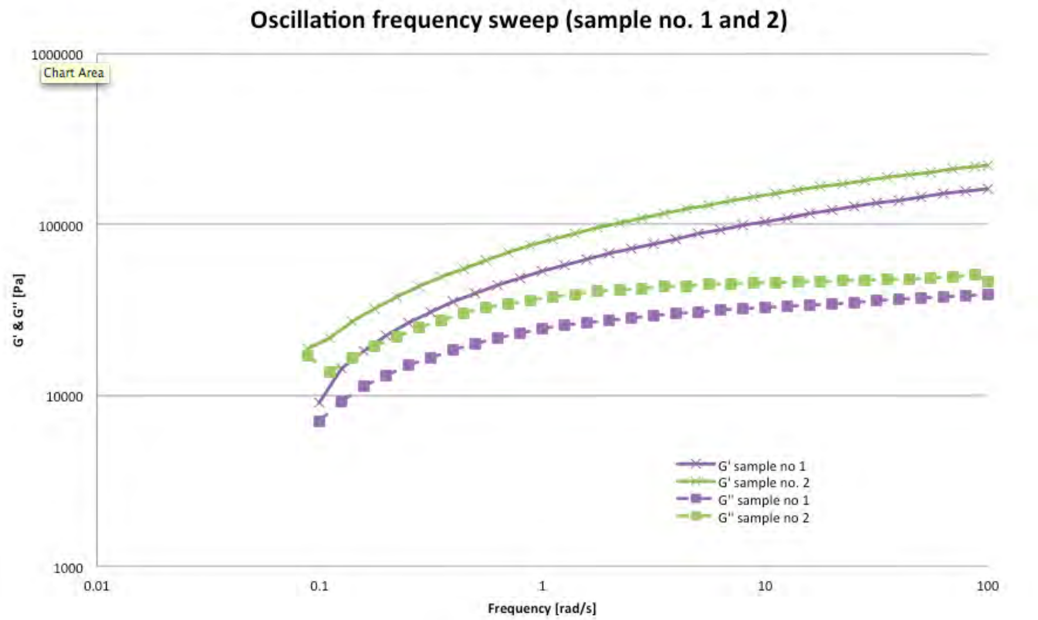

Fig. 3: First oscillation frequency sweep at 0.07 % strain for sample no 1 and 2

In 3 it is seen that the results are somewhat reproducible. It is seen that the viscosity for sample no two is slightly larger than for sample no. 2 which is in good agreement with the fact that sample no 2 is slightly more concentrated than sample no. 1.

In order to investigate the time evolution of the viscosity, an oscillation time sweep was performed for sample no 3 displayed in 4.

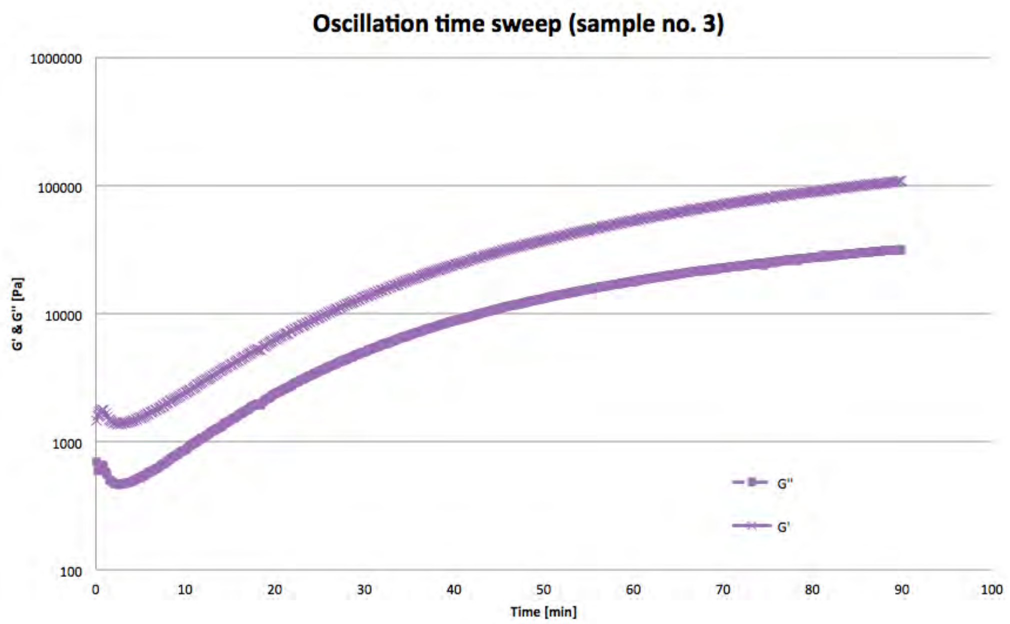

Fig. 4: Oscillation time sweep at 1Hz and strain of 0.07 %

It is seen that part from an initial period of three minutes where the sample seems to be sheer thinning, the viscosity increases with time. This is in good agreement with the increase in viscosity between the two runs for sample no 1 displayed in 2.

4 Discussion

Two phenomena are expected to cause the time dependent change in viscosity. The first is relaxation time. For short time scales (<5 minutes) the viscosity seems to decrease with time. This might be due an increasing alignment of the sugar molecules as time passes resulting in a lower viscosity than the initial viscosity. The second phenomenon is crystallization and it becomes apparent for longer timescales (hours). This results in an increasing viscosity with time. The explanation for the crystallization can be found from the phase diagram displayed in figure 5.

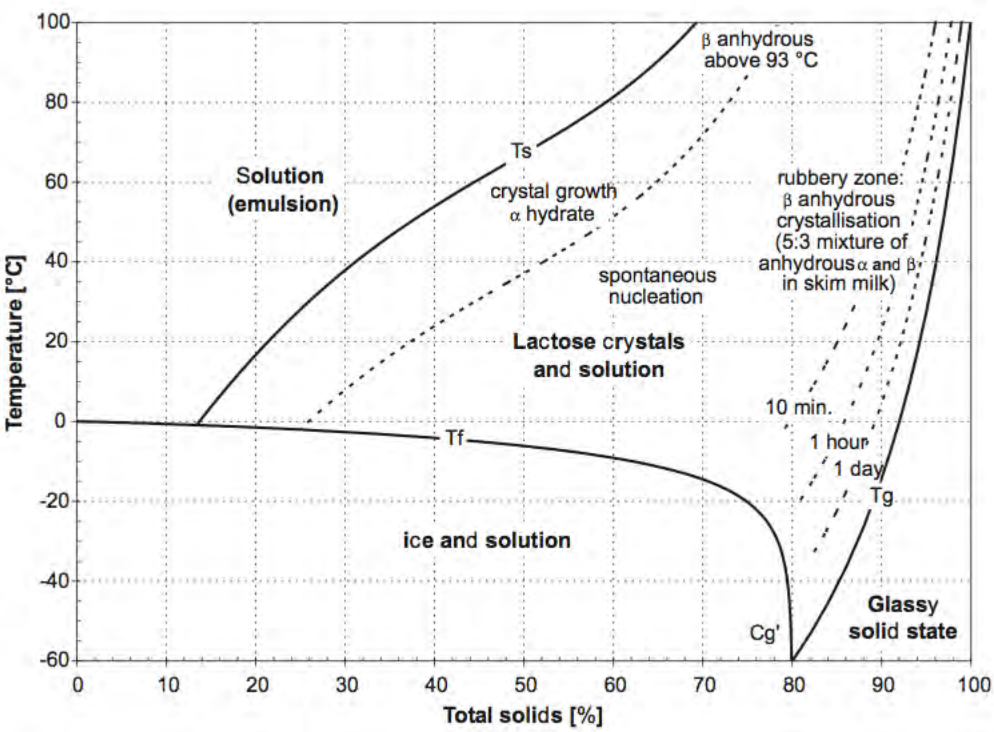

Fig. 5: Phasediagram for skimmilk [1]

In the phase diagram displayed in figure 5, it is seen that at high concentrations (85 to 95 % at 25^oC) the time at which the crystallization of lactose sets in is delayed. This is due to the fact that the mobility of the lactose molecules is reduced at these high concentrations. Therefore the time that it takes for a sample of high solid concentration to reach the amount of crystals predicted by the phase diagram could possibly be several hours. This could also be true for samples at lower concentrations and therefore the solutions from table 1.

These initial studies have shown that several phenomena influence the viscosity of the lactose solutions. In future studies it is important to avoid crystallization of the sample however the effect of sheer thinning is interesting to look further into.

5 References

[1] Vuataz, G.: *The phase diagram of milk: a new tool for optimising the drying process*, Lait 82 (2002) 485-500.